BBC

TOO FAST: THE SHOES BANNED AT THE OLYMPICS

Science Focus

THE BIG QUESTIONS

SPECIAL ISSUE

- Do we live in a simulation?
- How did life begin?
- Should we play with evolution?
- Are we getting happier?
- What happens when we die?
- Should we reach out to aliens?
- Is religion dying out?
- What are emotions?
- What's inside the fifth dimension?
- Can we cure old age?

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Icy plunge
Why doctors think you should try cold-water swimming

Dragon man
Meet the long-lost member of the human family

Artificial heart
A machine-based transplant Iron Man would be proud of

This was Sylvia's promise to you...

A generation ago, a woman named Sylvia made a promise. As a doctor's secretary, she'd watched stroke destroy the lives of so many people. She was determined to make sure we could all live in a world where we're far less likely to lose our lives to stroke.

She kept her promise, and a gift to the Stroke Association was included in her Will. Sylvia's gift helped fund the work that made sure many more of us survive stroke now than did in her lifetime.

Sylvia changed the story for us all. Now it's our turn to change the story for those who'll come after us.

Stroke still shatters lives and tears families apart. And for so many survivors the road to recovery is still long and desperately lonely. If you or someone you love has been affected by stroke – you'll know just what that means.

But it doesn't have to be like this. You can change the story, just like Sylvia did, with a gift in your Will. All it takes is a promise.

You can promise future generations a world where researchers discover new treatments and surgeries and every single stroke survivor has the best care, rehabilitation and support network possible, to help them rebuild their lives.

Big or small, every legacy gift left to the Stroke Association will make a difference to stroke survivors and their families.

Find out how by calling 020 7566 1505

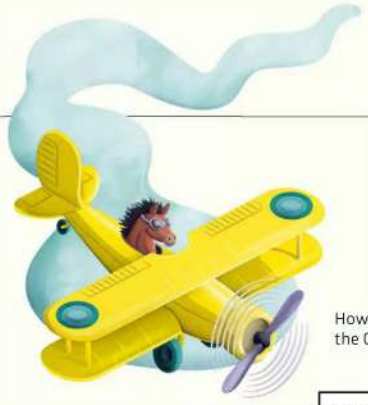
or email legacy@stroke.org.uk

or visit stroke.org.uk/legacy

Rebuilding lives after stroke

The Stroke Association is registered as a charity in England and Wales (No 211015) and in Scotland (SC037789). Also registered in the Isle of Man (No. 945) and Jersey (NPO 369), and operating as a charity in Northern Ireland.

Stroke Association



How do horses get to the Olympics? →p79

FROM THE EDITOR

Why on Earth does that fly keep slamming into the glass instead of leaving through the window I just opened? Is cracking my knuckles bad for me? Am I getting enough sleep? Well… it turns out flies just don't get the concept of glass, and hitting their head over and over can be fairly disorientating; cracking your knuckles is okay, even if your other half doesn't think so; and no, I'm definitely not getting enough sleep.

Why am I boring you with the mundane thoughts that go through my head? Well, I'm showing off really. You see, the best thing about working on *BBC Science Focus* is that we have a small army of world-leading scientists on hand to answer our every question (and they love doing it!). We're pretty sure that's one of your favourite things about the magazine too, so we thought we'd invite some of those experts to take over the magazine for an issue and answer a bunch of the really big questions.

We've thrown out some of the magazine regulars (don't worry, they'll be back next month) and turned the magazine into one giant Q&A. So if you want to find out what happens in your brain when you feel emotions (p60), whether we're likely to keep working 9-5 in the future (p59) or if we really need a grand theory of everything to understand the Universe as we know it (p68) then this is the issue for you.

If you find yourself wanting more, you ought check out our new podcast *Instant Genius* where you'll find bite-sized masterclasses on some of the most fascinating research in the world, including the science of brain chemistry, sleep, cooking and much more. Enjoy the issue!

Daniel Bennett, Editor

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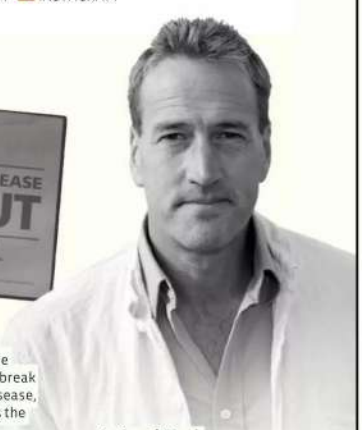
ON THE BBC THIS MONTH...

The Last Unicorn
This one-hour documentary follows wildlife conservationists' expedition to South Sudan, where they hope to find a population of northern white rhinos – a species officially declared extinct in 2018.
BBC Two, check *Radio Times* for details

Black Hill, Bleak Summer
Twenty years after the UK's biggest ever outbreak of foot and mouth disease, Dave Howard revisits the remote farming community where he grew up, to tell the story of its devastating impact there.
BBC Radio 4
27 July, check *Radio Times* for details



Animal Park
Ben Fogle (pictured), Kate Humble and the team at Longleat Estate return to our screens for more behind-the-scenes adventures at the safari park.
BBC One, check *Radio Times* for details

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DR LISA FELDMAN BARRETT
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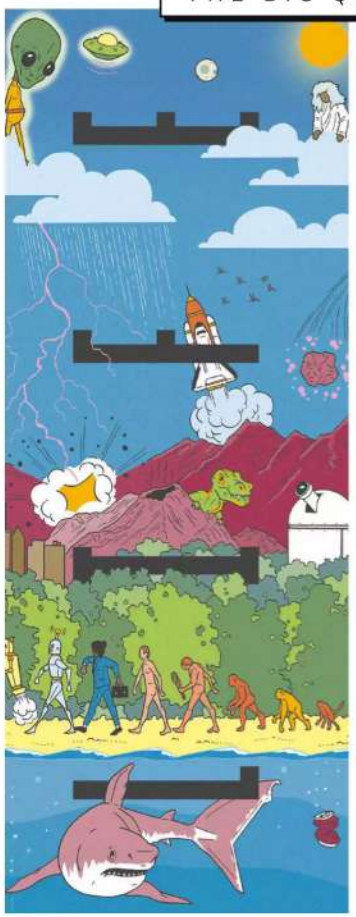

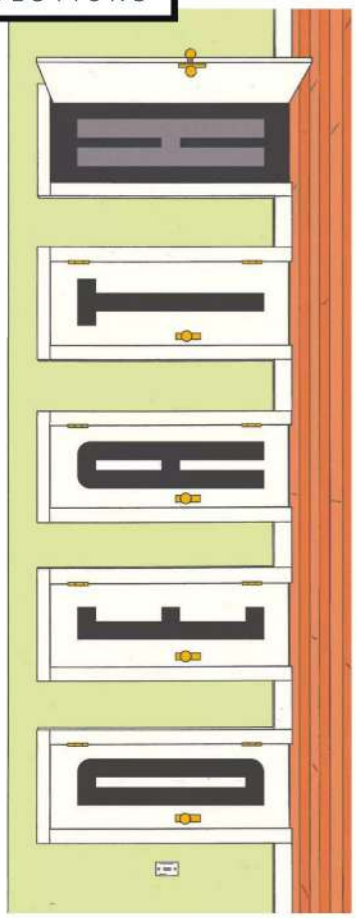

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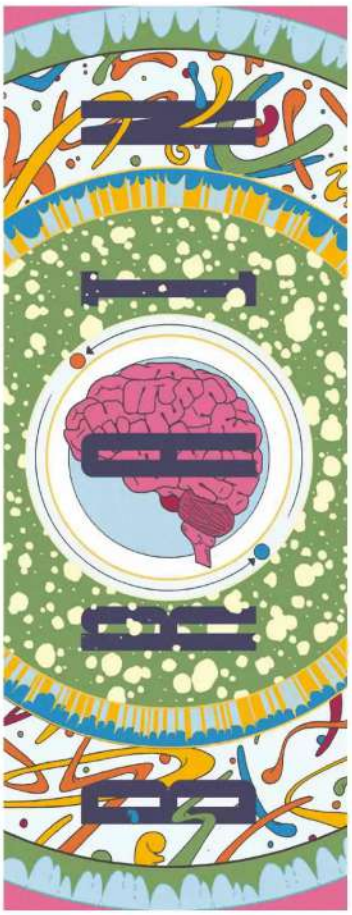

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What's inside the fifth dimension?

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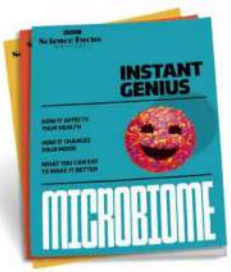

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EYE OPENER

Burrow bot

UNIVERSITY OF CALIFORNIA, SANTA BARBARA, USA

Robots have helped us explore the world, from the ocean's depths to mountain peaks, and even outer space. But while robots can swim, run and fly like their biological counterparts, engineers have struggled to build a bot that burrows as well as an animal. Until now...

To design a bot capable of navigating the subterranean world, researchers at the University of California and the Georgia Institute of Technology decided to take inspiration from nature.

To travel vertically down, the team's 'soft' robot acts like a plant's root system by using an extending tip to push surrounding material out of its way. To move horizontally, the robot imitates the burrowing sand octopus: blowing air from its tip in opposite directions to loosen up the sand standing in its way.

The team is working with NASA to develop a robot that can burrow into the surface of the Moon.

COVER IMAGES

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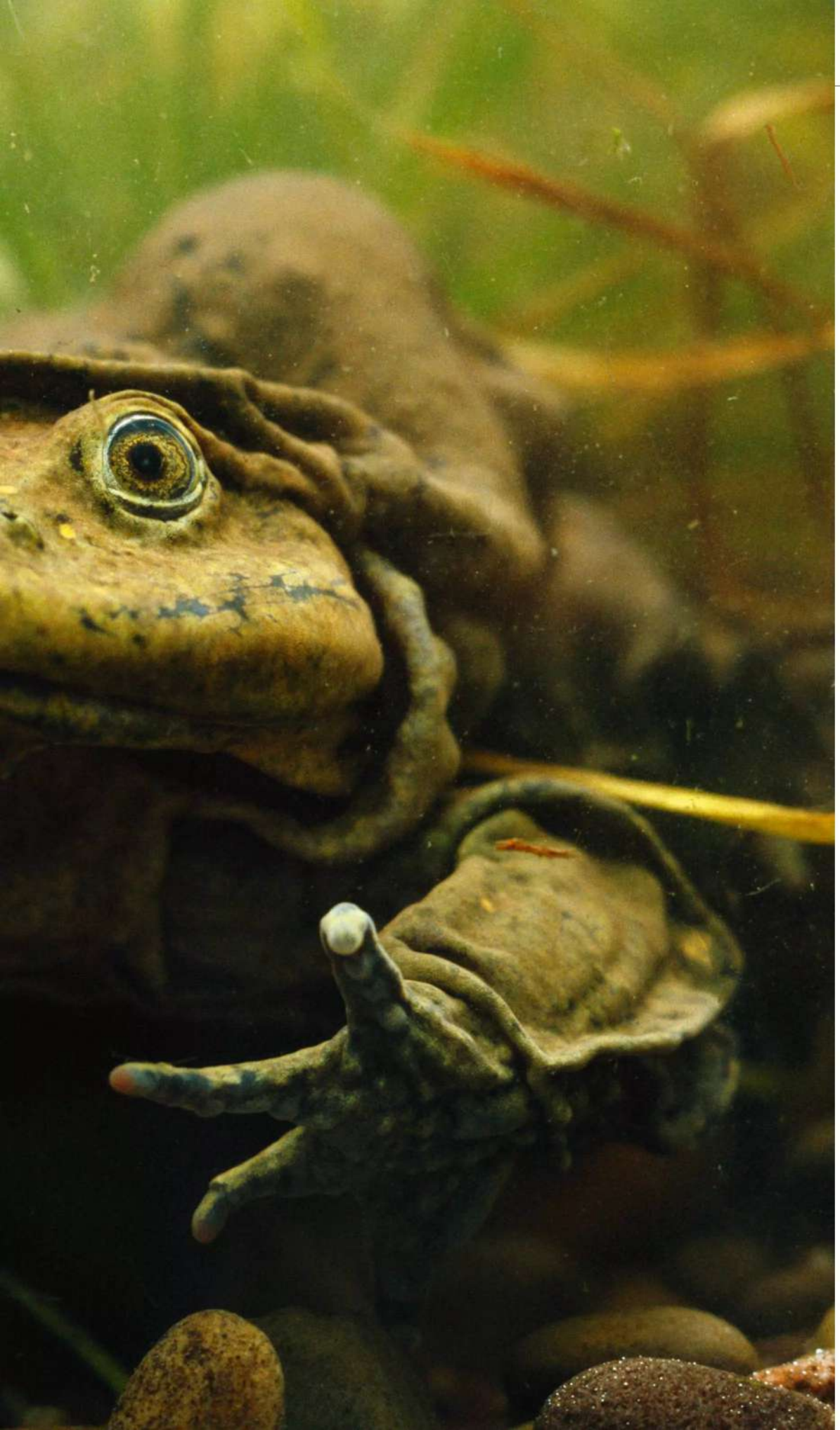

EYE OPENER

A breath of freshwater

LAKE TITICACA,
BOLIVIA AND PERU

Telmatobius culeus is a giant frog that lives in Lake Titicaca – 3,812 metres above sea level. To live at such a high altitude, the frog has had to adapt its movement, metabolism, and even its skin.

T. coleus is entirely aquatic. Its lungs are poorly developed, but its baggy skin contains vast amounts of capillaries that enable the amphibian to absorb oxygen from the water. Its many folds – affording it the nickname 'scrotum frog' – increase the skin's surface area to maximise oxygen intake.

If it starts to run out of oxygen, the frog bobs up and down to create ripples that let oxygen-rich water flow over its skin. While it's the largest aquatic frog (reportedly reaching lengths of up to 60cm, with its legs outstretched), it has the slowest metabolism of all frogs, to lessen its demand for oxygen.

Frogs have long been used for medicinal purposes in Peru, and due to poaching and pollution of the lake, the frog is now classed as endangered.

PETE OXFORD/MINDEN PICTURES

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CONVERSATION

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LETTER OF THE MONTH

Cats love all boxes, even those that are optical illusions

Purrrrrfect physics

Aaaah! An experiment to prove that cats like virtual boxes (June, p22). Yet another quantum effect.

I'm surprised that Erwin Schrödinger didn't capitalise on cats' liking for imaginary boxes when conducting his famous 'Schrödinger's cat' experiment. How much easier it would have been for him to see the kitty's waveform collapsing (or not) if it had been in an illusory box!

What box? Pooof!

Err... what cat?

Martin Kirby-Sykes

WRITE IN AND WIN!

The writer of next issue's *Letter Of The Month* wins a two-metre-long LIFX Lightstrip for highlighting any space. The Lightstrip features LIFX's unique Polychrome Technology, with over eight addressable colour zones per light strip and millions of colours to choose from. Perfect for parties, gaming nights, and updating your working from home space, you can control the strip via the accompanying app. **uk.lifx.com**

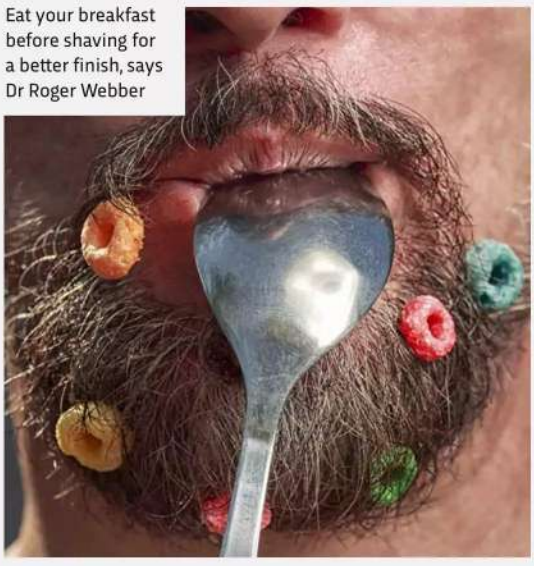
Eat cereal, then shave

While I am sure that all the things mentioned by Dr Mary Sommerlad (June, p90) are important in getting the ultimate shave, timing is everything. While you are lying down your body fluids are rearranged so that immediately on getting up you have a slightly puffy face. If this is allowed to drain back to your lower body, say have your breakfast before you shave, then this facial oedema will have decreased and you will get a closer shave.

Dr Roger Webber

Why not hydrogen?

The current drive to all-electric cars suffers from a basic flaw: there are not enough rare earth minerals to supply all the batteries' needs. As the supply of rare earth minerals dwindles, the price is sure to increase. Surely it would be simpler to convert petrol internal combustion engines to run on hydrogen. Engine manufacturers have more than a century of development to fall back on. There



Eat your breakfast before shaving for a better finish, says Dr Roger Webber

"THE TINY PLANET WE FIND OURSELVES ON – THIS PALE BLUE DOT FLOATING IN SPACE – COULD BE THE MOST IMPORTANT PLACE IN THE ENTIRE COSMOS"

LORD MARTIN REES, P30

Why can't we roll out hydrogen cars, ponders Dave Newbury

would be no need to roll out a totally new network of charging points if the service stations could be converted to supply pressurised hydrogen more cheaply and instantly.

Dave Newbury

Lunar confusion

In the article about going back to the Moon (April, p60), it is stated that "the Sun is constantly overhead when you are at the lunar equator".

Surely not.

My understanding is that, at the lunar equator, the Sun would track from due east to due west and would only be directly overhead at lunar noon. Each point on the equator would experience sunlight for half the time and be in night the other half. Have I got it right?

Eric McCrossan

The point I was making here was that the Sun would always be overhead at lunar noon, regardless of the time of year. Here on Earth, the Sun is only directly overhead at the equator on the two equinoxes. I did however, leave out the 'at lunar noon' caveat. What I was trying to say was that the equator gets the maximum amount of Sun, while the poles get hardly any.

Dr Elizabeth Pearson, *astrophysicist*

GETTY IMAGES X4

The Sun is only directly overhead at the equator on the two equinoxes

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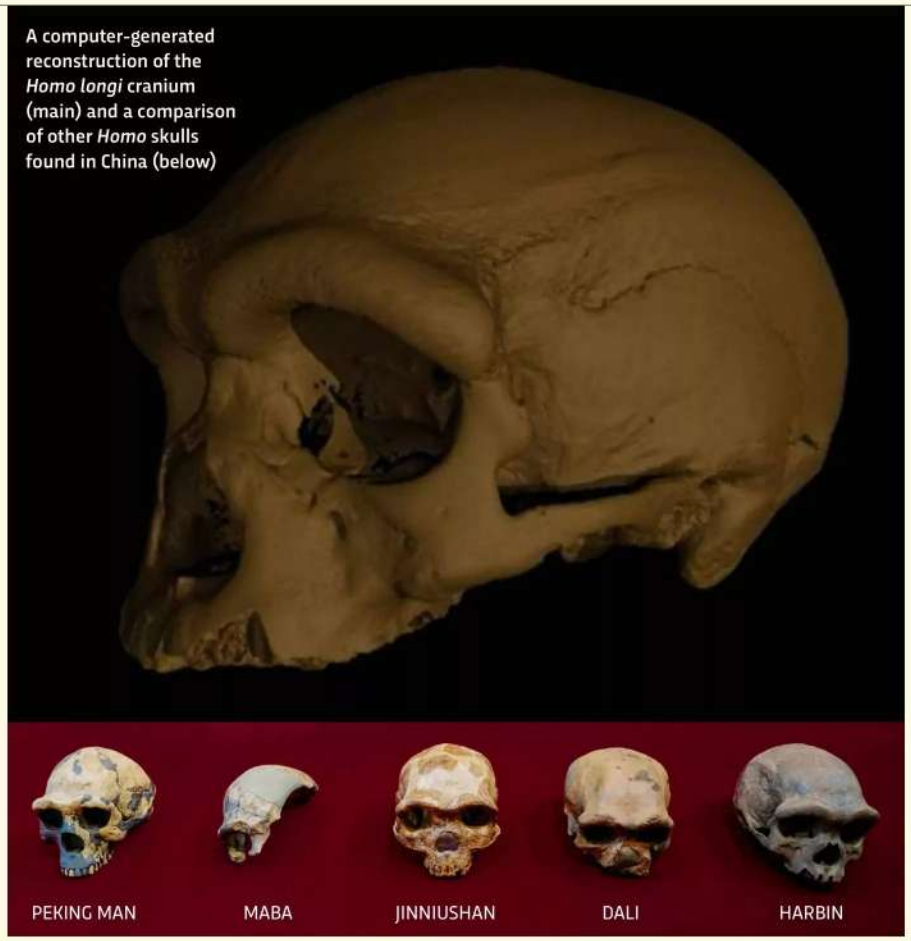
DISCOVERIES

'DRAGON MAN' MAY HAVE BEEN HUMANS' CLOSEST RELATIVE

Analysis of a fossil found in China in the 1930s could reshape our understanding of human evolution, researchers say

CHUANG ZHAO

Simulation stimulation Rats' brain activity boosted by virtual reality p19 **Supermassive secrets** Dark matter may be behind the growth of supermassive black holes p21 **Six-hour spacewalk** Astronauts install a new solar array on the International Space Station p22



A computer-generated reconstruction of the *Homo longi* cranium (main) and a comparison of other *Homo* skulls found in China (below)

A newly identified species of ancient hominin may be the closest relative to modern humans ever discovered, a team of international researchers has claimed.

Named *Homo longi*, or 'Dragon Man', the new species was identified from a near-perfectly preserved fossil known as the Harbin cranium, which was unearthed in Harbin City in northeastern China in the 1930s. The name comes from the province where Harbin City is found: Heilongjiang, which translates as 'Dragon River'.

H. longi's large skull could house a brain similar in size to that of modern humans, but had larger eye sockets, heavy, prominent brow ridges and a wide gaping mouth containing large, well-developed teeth.

"The Harbin fossil is one of the most complete human cranial fossils in the world," said Qiang Ji, a professor of palaeontology of Hebei GEO University, where the fossil is stored.

"This fossil preserved many morphological details that are critical for understanding the evolution of the *Homo* genus and the origin of *Homo sapiens*. While it shows typical archaic human features, the Harbin cranium presents a mosaic combination of primitive and derived characteristics, setting itself apart from all the other previously named *Homo* species."

The researchers believe that the cranium belonged to a male who was around 50 years old at the time of his death. They think *H. longi* would have lived in small communities in forests. The cranium suggests that the Harbin individual was very large, so it's likely *H. longi* was well adapted for survival in harsh environments and may have been successful enough to disperse all over Asia, they say.

"The team estimates the Harbin fossil to be at least 146,000 years old, dating it back to the Middle Pleistocene"

The team estimates the Harbin fossil to be at least 146,000 years old, dating it back to the Middle Pleistocene. It's likely to have been around at the same time as Denisovans, Neanderthals and *H. sapiens*, and may even have interacted with ancient humans.

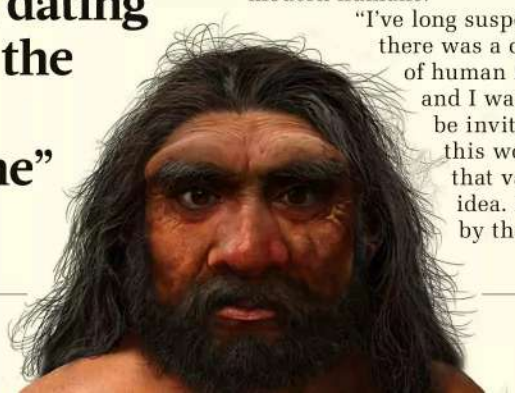
After hours of work piecing together how *H. longi* fits into the hominin family tree, the team discovered that it was one of the closest relatives to modern humans.

"I've long suspected that there was a distinct species of human in East Asia and I was delighted to be invited to study this wonderful fossil that validated the idea. I was surprised by the resulting phylogeny linking it to *H. sapiens* rather than *H. neanderthalensis*, but our conclusions are based on the analysis of large amounts of data," said Prof Chris Stringer, a palaeoanthropologist at the Natural History Museum in London.

"The analyses employed over 600 traits, equally weighted, and millions of tree-building processes to arrive at the most parsimonious trees. It establishes a third human lineage in East Asia with its own evolutionary history and shows how important the region was for human evolution."

Their reconstruction of the human tree of life also suggests that the common ancestor we share with Neanderthals existed even further back. If true, we likely diverged from Neanderthals roughly 400,000 years earlier than scientists had thought.

"It's widely believed that the Neanderthal belongs to an extinct lineage that is the closest relative of our species. But our discovery suggests that the new lineage we identified that includes *H. longi* is the sister group of *H. sapiens*," said Xijun Ni, a professor of primatology and palaeoanthropology at the Chinese Academy of Sciences.



KAI GENG, CHUANG ZHAO, GETTY IMAGES; ILLUSTRATION: KYLE SMART

MEDICINE

What's the best way to create a malaria vaccine? Make a mosquito smoothie!

Everyone likes a fruity smoothie in the summer, but a mosquito smoothie might be more beneficial for your health.

Scientists at Imperial College London have developed a new way of extracting malaria parasites from infected mosquitoes by processing the insects into a slurry, then filtering out the parasites to use in the vaccine. The method allows more parasites to be extracted faster with less contamination, and could lead to the development of better malaria vaccines.

The malaria parasite, *Plasmodium*, is spread through the bites of infected female *Anopheles* mosquitoes. *Plasmodium* is becoming more resistant to antimalarial drugs, while mosquitoes are becoming more resistant to pesticides. Finding better ways of treating malaria is therefore a matter of urgency, as the disease claims 400,000 lives per year, 61 per cent of which are children under five.

The existing method of creating malaria vaccines requires highly skilled technicians to dissect young parasites (known as sporozoites) from the mosquitoes' salivary glands. The parasites are then 'attenuated', so they produce an immune response in the body without causing illness. Several doses of these vaccines are needed, with each dose potentially requiring hundreds of thousands of sporozoites.

The new method is much faster and doesn't require any fiddly dissection.

"Creating whole-parasites vaccines in large enough volumes, and in a timely and cost-effective way, has been a major roadblock for advancing malaria vaccinology, unless you can employ an army of skilled mosquito dissectors," said lead researcher Prof Jake Baum. "Our new method presents a way to radically cheapen, speed up and improve vaccine production."

But speed and cost aren't the only benefits. The scientists found that the sporozoites extracted using the new method came with fewer contaminants than the traditional method. They were also more infectious, which may allow vaccines to use lower sporozoite doses.

"With this new approach we not only improve the scalability of vaccine production, but our isolated sporozoites may prove to be more potent as a vaccine, giving us additional bang per mosquito buck," said first author of the study Dr Joshua Blight.

The new vaccine showed good results in rodent tests, providing 100 per cent protection from malaria. The researchers are now scaling up the process so they can start human trials.

Malaria parasites take up residence in the salivary glands of mosquitoes, and are transferred to the victim when the insect bites

COFFEE DRINKERS

Whether your go-to is a double decaf latte with mocha sprinkles or a plain old black Americano, drinking coffee can reduce your chances of developing liver disease by 20 per cent, a study at the University of Southampton has found.

CHOCOHOLICS

It turns out breakfast really is the most important meal of the day! Eating chocolate within an hour of waking may help us to burn more fat and lower glucose levels, according to research by a team at Brigham and Women's Hospital in Boston, US.

Good month

Bad month

THE TONGUE-TIED

According to a survey by the insights agency Perspectus Global, 61 per cent of Brits find it irritating when people mispronounce words. The top offenders were 'pacifically' instead of 'specifically', which 35 per cent said was irritating; 'probly' instead of 'probably' (28 per cent); and 'expresso' instead of 'espresso' (26 per cent).

UNHAPPILY MARRIED MEN

Men who perceive their marriages to be a failure are 21 per cent more likely to die prematurely than those in happy relationships, a 30-year study of 10,000 men carried out at Tel Aviv University has found.

SPACE

Betelgeuse's brightness dimmed, and we finally understand why

Astronomers have discovered the cause of the 'Great Dimming of Betelgeuse': a cloud of dust partially concealing it from us.

As one of the largest stars visible to the naked eye, the red supergiant star Betelgeuse is a familiar sight to professional and amateur astronomers alike. That's perhaps why it was so surprising when the star's brightness started to drop in October 2019.

By February 2020, the star, which marks the right shoulder in the constellation of Orion, had hit a record low of only 40 per cent of its usual brightness.

This dramatic drop sparked speculation that Betelgeuse was about to go supernova – that is, reach the end of its life as a red supergiant, collapse, and then bounce into a fiery explosion so bright we'd even be able to see it in the daytime. It wasn't immediately clear to astronomers whether or not this was the case, since a supernova hasn't been observed in our Galaxy since astronomer Johannes Kepler saw one in 1604.

But it never happened, and by April 2020, Betelgeuse was back to its normal brightness. Now, images of the star, taken with the European Southern Observatory's Very Large Telescope, along with data from the GRAVITY instrument, have revealed what happened to it.

"We have directly witnessed the formation of so-called stardust," said Dr Miguel Montargès, from the Observatoire de Paris, France, and KU Leuven, Belgium. "For once, we were seeing the appearance of a star changing in real time on a scale of weeks."

The surface of Betelgeuse is always changing. Giant bubbles of gas grow, shrink and move around within the star, and occasionally it burps one out. Before the Great Dimming began, Betelgeuse released one of these bubbles. Then a patch of the star's surface cooled down, and this temperature drop allowed the gas to cool enough to condense into solid dust.

This cloud of dust partially concealed Betelgeuse from the Earth, particularly in the southern region.

"The dust expelled from cool evolved stars, such as the ejection we've just witnessed, could go on to become the building blocks of terrestrial planets and life," said Emily Cannon, a PhD student at KU Leuven. "Looking up at the stars at night, these tiny, twinkling dots of light seem perpetual. The dimming of Betelgeuse breaks this illusion."

In the image on the far left, taken in January 2019, you can see Betelgeuse at its normal brightness. The other images, from December 2019, January 2020 and March 2020, show the star dimming

NEUROBIOLOGY

Birds' brain activity translated into song

The findings could allow scientists to design high-quality vocal prosthetics for people who can no longer speak

Here's something worth tweeting about: researchers have managed to synthesise birds' brain activity into song.

The scientists, who come from the University of California, San Diego, say that this research could help create a means of communication for people who are no longer able to speak.

Current state-of-the-art communication prosthetics are implantable devices that allow the user to generate text at a speed of about 20 words per minute.

"Now imagine a vocal prosthesis that enables you to communicate naturally with speech, saying out loud what you're thinking nearly as you're thinking it," said senior author Timothy Gentner, a professor of psychology and neurobiology at UC San Diego. "That is our ultimate goal, and it is the next frontier in functional recovery."

While human speech and birdsong might not seem immediately comparable to each other, the researchers say that there are a lot of similarities, as both types of vocalisation are learned and complex behaviours.

GETTY IMAGES, ESO/M MONTARGES ET AL. ILLUSTRATION: KYLE SMART

Male zebra finches, like this one on the right, will learn to sing by imitating their fathers and other adult males

The team implanted electrodes into the brains of four male zebra finches and read their brain activity while they sang. Specifically, they monitored the electrical activity in regions of the brain that control the muscles responsible for singing. They then fed this information into a machine-learning algorithm, with the idea that they'd be able to create computer-generated versions of the zebra finches' songs using just their neural activity. This was not easy.

"There are just too many neural patterns and too many sound patterns to ever find a single solution for how to directly map one signal onto the other," said Gentner.

To overcome this hurdle, the team designed some mathematical equations that modelled physical changes that happen in the birds' vocal organ (the syrinx) when they sing. They then trained the algorithms to map the neural activity onto these equations.

"If you need to model every little nuance, every little detail of the underlying sound, then the mapping problem becomes a lot more challenging," said co-author Vikash Gilja, a professor of electrical and computer engineering at UC San Diego. "By having this simple representation of the songbirds' complex vocal behaviour, our system can learn mappings that are more robust and more generalisable to a wider range of conditions and behaviours."

Next, the researchers want to create a way of reconstructing neural activity to birdsong in real time. According to Gentner, this would help them to develop a successful vocal prosthesis that could operate on a rapid timescale, and also make adjustments for any errors.

"We are leveraging 40 years of research in birds to build a speech prosthesis for humans – a device that would not simply convert a person's brain signals into a rudimentary set of whole words, but give them the ability to make any sound, and so any word, they can imagine, freeing them to communicate whatever they wish," he said.

The research is published in the journal *Current Biology*.

They did what?

Crayfish given antidepressants

WHAT DID THEY DO?

A team at the University of Florida placed 20 crayfish into sheltered watery mazes with two exits, one spiked with food and the other laced with the scent of another crayfish. They then exposed half of them to selective serotonin inhibitors, a type of antidepressant, and compared the behaviour of the two groups.

WHAT DID THEY FIND?

The crayfish that were exposed to antidepressants emerged from the shelter sooner and spent three times as long in the food-scented area – this indicates that they were 'bolder' and may be more susceptible to predators. Though this may seem insignificant, over time it could have a noticeable effect on the ecosystem.

WHY DID THEY DO THAT?

Antidepressants frequently make their way into waterways, thanks to low levels of them being excreted or incorrectly disposed of by humans. The team wanted to investigate any detrimental effect this might have on wildlife.

MINERALOGY

Joke's on us: fool's gold may have contained the real thing all along

The mineral pyrite has another name: fool's gold, as its metallic yellow crystals trick miners into thinking they've struck real gold. It's not without its uses – the compound creates sparks when hit with steel, which can be used to start a fire – but it's always been seen as worthless compared to its coveted cousin.

Now, scientists have discovered that the mineral, made of iron and sulphur, actually contains a type of gold hidden within its crystal structure. Research suggests that extracting this gold could be a more sustainable method of getting the metal than current energy-intensive mining processes.

Fool's gold is found inside rocks beneath Earth's surface, sometimes near real gold deposits. The mineral has a crystalline structure, which grows over the years and stretches within the rock. Each time the crystals stretch and twist, they break the bonds of nearby atoms. When these bonds are remade, they can sometimes contain small imperfections, areas called 'dislocations' that are each around 100,000 times smaller than the width of a human hair.

According to new research, these tiny dislocations can actually contain gold particles.

"Our research shows that gold can be captured when the crystals are being twisted during their history," said the lead researcher of the new study, Dr Denis Fougerouse from Curtin University in Western Australia.

This gold is different to the gold of your wedding band or filling: it's known as 'invisible' gold because it comes in such small quantities that it can't be detected by a microscope. Instead, an atom probe is needed to analyse the tiny amounts found within pyrite's crystal structure.

"[Invisible] gold is not as valuable as 'free gold', where the gold is available by simple physical separation," explained Fougerouse. "But it's still profitable with the right infrastructures and just as precious as any other kind of gold."

Gold has also been found in fool's gold in the form of an alloy, where the pyrite and gold atoms are mixed together. "It's possible that the gold used to make the jewellery you like could have been extracted from pyrite originally," said Fougerouse. To extract the gold from these minerals however, miners need to use large reactors that require huge amounts of energy to run.

Fougerouse and the team hope that their new discovery could lead to better, more environmentally friendly ways to mine gold. They've come up with a (currently untested) process for leaching the gold particles from the pyrite crystals, and even suggest using bacteria to 'attack' the dislocations to break down the crystal structure and release the gold.

But it would be foolish to think our future fillings and wedding rings will be made from pyrite's 'invisible gold'.

"Pyrite is a very common mineral and only pyrites that crystallised in the right geological setting will host significant gold," said Fougerouse. "Some pyrites still live up to their reputation of fool's gold!"

Iron pyrite (above and below), otherwise unflatteringly known as fool's gold

NEUROLOGY

VR may strengthen your brain waves – and be an effective Alzheimer's treatment

A new study on rats demonstrated how virtual reality strengthened crucial 'theta waves' in the hippocampus

Virtual reality can boost brain activity that may be crucial for learning, memory and even treating Alzheimer's, ADHD and depression, a study on rats has found.

After monitoring the animals' brain activity with tiny electrodes, researchers from the University of California Los Angeles (UCLA) discovered electrical activity in a region known as the hippocampus differed depending on whether the rodents were placed in real-world or virtual reality (VR) environments. (Before you ask: no, the rats weren't fitted with tiny VR headsets. They were placed on a small moving track surrounded by screens.)

The new findings are significant as the hippocampus is a primary driver of learning and memory, including spatial navigation, in the brain.

When rats walk around in real life, electrical activity in the hippocampus neurons appears to synchronise, at a rate of eight pulses per second (8Hz). Pulses at this frequency are generally known as 'theta waves', with stronger theta waves seeming to improve the brain's ability to learn and retain sensory information. When placed in a VR environment, the rat's theta waves became considerably stronger.

"It turns out that amazing things happen when the rat is in virtual reality," said Prof Mayank Mehta from the Center for Neurophysics at UCLA. "We were blown away when we saw this huge effect of VR experience on theta rhythm enhancement."

The scientists also found that VR environments altered different electrical rhythms in different parts of the neurons. "That was really mind-blowing," Mehta said. "Two different parts of the neuron are going in their own rhythm."

More interestingly, this new brain rhythm (which the UCLA scientists dubbed 'eta') was also strengthened in the VR environment.

All this indicates that scientists may be able to manipulate human brain rhythms in VR – not only to boost learning, but also to treat memory-related disorders including ADHD, autism, Alzheimer's disease, epilepsy and depression.

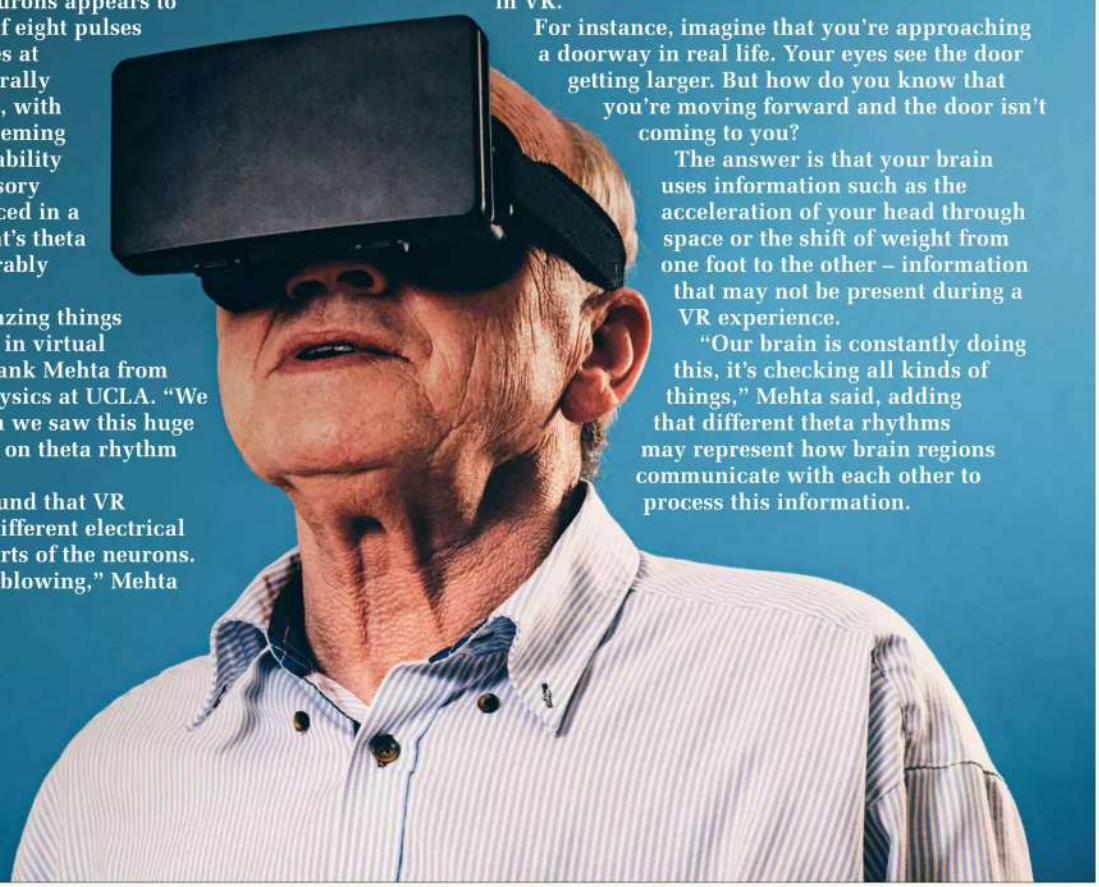
"This is a new technology that has tremendous potential," Mehta said. "We've entered a new territory."

The study also indicates why VR may encourage these unique brain waves. A big part of it, Mehta theorises, may be down to the very different set of stimuli presented in VR.

For instance, imagine that you're approaching a doorway in real life. Your eyes see the door getting larger. But how do you know that you're moving forward and the door isn't coming to you?

The answer is that your brain uses information such as the acceleration of your head through space or the shift of weight from one foot to the other – information that may not be present during a VR experience.

"Our brain is constantly doing this, it's checking all kinds of things," Mehta said, adding that different theta rhythms may represent how brain regions communicate with each other to process this information.



VR has an effect on brain activity that may have uses as a treatment for neurological disorders

GETTY IMAGES X2, ALAMY

Imaging techniques highlight different cells found in the kidney organoids

MEDICINE

Science's new weapon against kidney disease: tiny lab-grown organoids

Researchers from the Keck School of Medicine of the University of Southern California have made a major breakthrough in creating tissues that mirror parts of the kidney

Up yours, kidney disease! That's what we imagine researchers from the Keck School of Medicine of the University of Southern California bellowed after successfully growing parts of a kidney in the lab – a move that could lead to new patient treatments.

Using stem cells, the team was able to create rudimentary cell structures, known as organoids, that mimic some functions of the real organ. Specifically, the new organoids resemble the collecting duct system that concentrates and transports urine, maintaining the body's fluid and pH balance.

With such an accurate model of the kidney, researchers could use it to screen potential therapeutic drugs.

Furthermore, the organoids can be genetically engineered to harbour mutations that cause disease, providing scientists with a better idea of how to tackle such illnesses.

In fact, the team behind the study has already tried this out, manipulating genes to create an organoid model that mirrors a condition known as CAKUT (congenital anomalies of the kidney and urinary tract).

"Our progress in creating new types of kidney organoids provides powerful tools for not only understanding development and disease, but also finding new treatments and regenerative approaches for patients," explained Prof Zhongwei Li, one of the scientists behind the breakthrough.

As outlined in the journal *Nature Communications*, the tiny kidney models were made by studying animal and human UBPCs (ureteric bud progenitor cells), which play a key role in early kidney development. From this, researchers were able to identify a "cocktail of molecules" that bound together to create organoids.

The development is a major stepping stone to creating a full synthetic organ. The team is already using similar methods to build models of other kidney parts, such as nephrons (the filtering units of the kidney), which are being grown using mice UBPCs.

In recent months, other groups of scientists have been able to produce organoid models of the heart, tear ducts, and even human, gorilla and chimpanzee brains.

In numbers

100 YEARS

The lifespan of a coelacanth (a species of fish that's been around since the age of the dinosaurs), as estimated by researchers at the University of Montpellier, France.

£20 MILLION

The price paid by a mystery bidder to bag a seat on the first crewed spaceflight on Amazon billionaire Jeff Bezos's Blue Origin reusable rocket.

13 TESLA

The strength of the gigantic magnet set to be installed in Europe's ITER nuclear fusion reactor. That's nearly 300,000 times the strength of Earth's magnetic field.

ZIPENG ZENG/LI LAB, GETTY IMAGES

SPACE

Supermassive black holes may be formed by collapsing dark matter halos

The theory may help to explain the presence of supermassive black holes in the early Universe

Supermassive black holes (SMBHs) are thought to be lurking at the centre of every galaxy, but very little is known about their origins. Current thinking suggests that these cosmic behemoths, which can have masses millions of times that of the Sun, would grow relatively slowly as it would take a considerable amount of time for them to suck in the matter that surrounds them.

There must be something else going on, however, as several supermassive black holes have been observed that date back to the early days of the Universe.

Now, physicists at the University of California think they may have an explanation: seed black holes, or black holes in their initial stages, can be formed by the collapse of the dark matter halos that surround galaxies.

"Physicists are puzzled why SMBHs in the early Universe, which are located in the central regions of dark matter halos, grow so massively in a short time," said study leader Hai-Bo Yu, an associate professor of physics and astronomy at the University of California Riverside, who led the study. "It's like a five-year-old child that weighs, say, 200lbs [90kg]. Such a child would astonish us all because we know the typical weight of a newborn baby and how fast this baby can grow. When it comes to black holes, physicists have general expectations about the mass of a seed black hole and its growth rate. The presence of SMBHs suggests these general expectations have been violated, requiring new knowledge. And that's exciting."

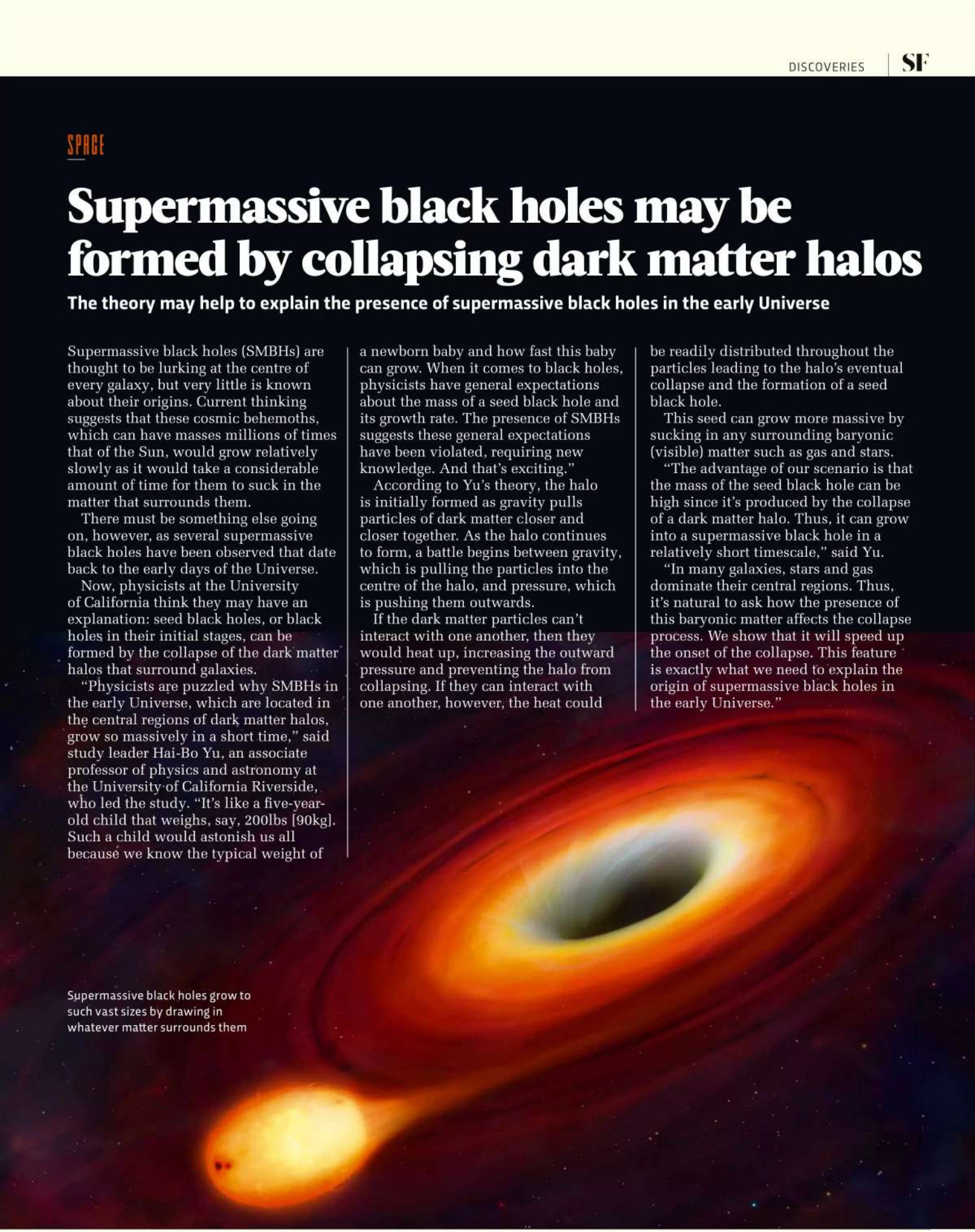
According to Yu's theory, the halo is initially formed as gravity pulls particles of dark matter closer and closer together. As the halo continues to form, a battle begins between gravity, which is pulling the particles into the centre of the halo, and pressure, which is pushing them outwards.

If the dark matter particles can't interact with one another, then they would heat up, increasing the outward pressure and preventing the halo from collapsing. If they can interact with one another, however, the heat could be readily distributed throughout the particles leading to the halo's eventual collapse and the formation of a seed black hole.

This seed can grow more massive by sucking in any surrounding baryonic (visible) matter such as gas and stars.

"The advantage of our scenario is that the mass of the seed black hole can be high since it's produced by the collapse of a dark matter halo. Thus, it can grow into a supermassive black hole in a relatively short timescale," said Yu.

"In many galaxies, stars and gas dominate their central regions. Thus, it's natural to ask how the presence of this baryonic matter affects the collapse process. We show that it will speed up the onset of the collapse. This feature is exactly what we need to explain the origin of supermassive black holes in the early Universe."



Supermassive black holes grow to such vast sizes by drawing in whatever matter surrounds them

SPACE

Astronauts install a new solar power array on the ISS during an epic six-hour spacewalk

Two astronauts from NASA and the European Space Agency have successfully installed the first of six new solar arrays on the International Space Station (ISS).

The mission is the first step in a programme to increase the power-generation capacity of the ISS to meet future demands, including Artemis – NASA's planned crewed mission to the Moon, currently scheduled for 2023.

Some of original arrays have been in place for 20 years and are showing signs of age. The six new arrays will be installed directly on top of the existing ones and generate roughly the same amount of power, despite only being half the size. Once fully installed, the arrays will be able to supply power to the ISS until 2030.

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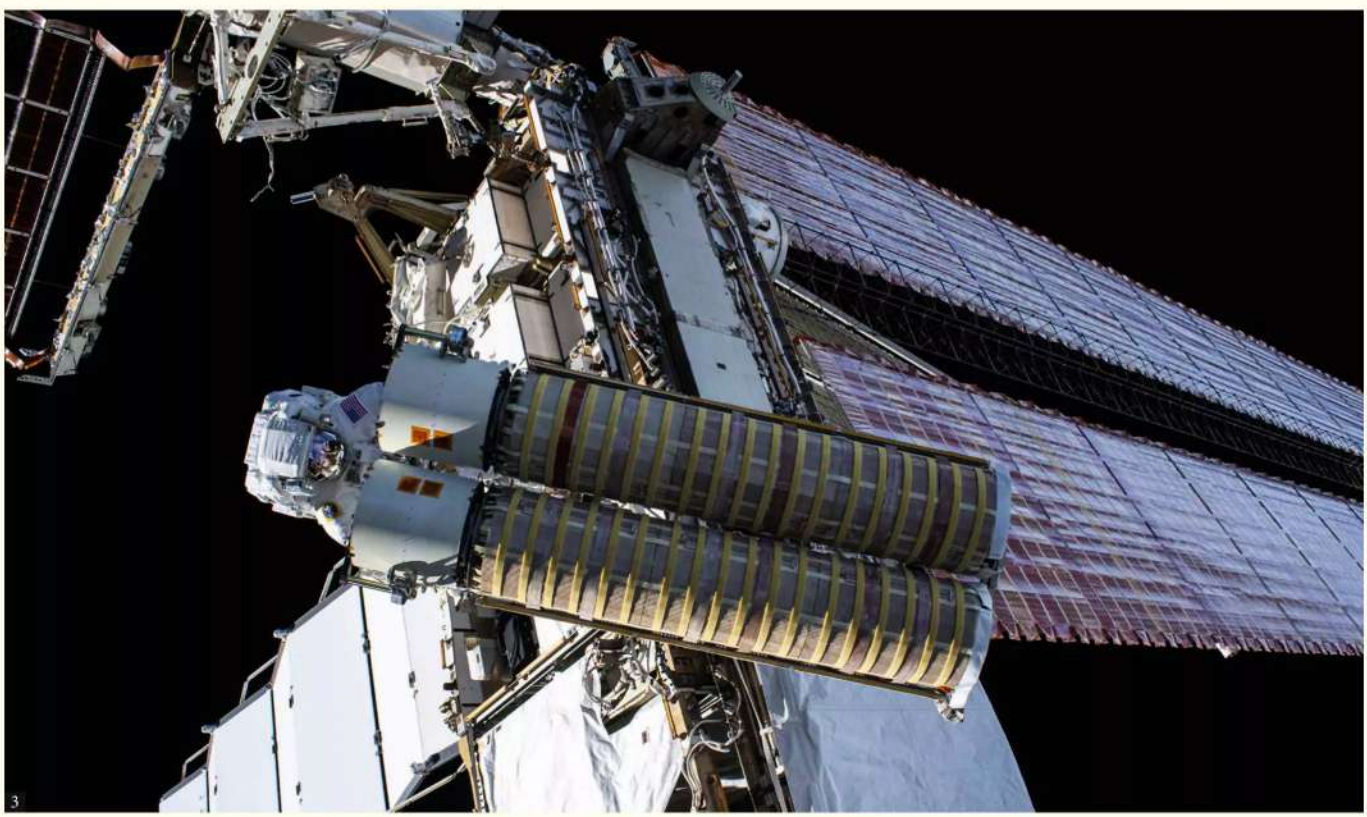
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DEPLOYABLE SPACE SYSTEMS, NASA/JOHNSON X4

1. The solar arrays were constructed by engineers at Deployable Space System's facility in Goleta, California and each measures 19 x 6 metres. The cells that make up the arrays were manufactured by Spectrolab, a company based around 160km (100 miles) down the road in Sylmar, and are some of the most powerful ever launched into space.

2. Commander Shane Kimbrough, along with pilot Megan McArthur and mission specialists Akihiko Hoshide and Thomas Pesquet, travelled to the ISS aboard a SpaceX Crew Dragon Endeavour spacecraft in April to prepare for the installation.

3. While the station's original arrays fold up and deploy in an accordion-like manner, the new arrays roll out like a carpet from inside a cylindrical canister.

4. NASA's Kimbrough and the European Space Agency's Pesquet spent six hours and 28 minutes on the outside of the station, slowly unfurling the new array and moving it into place. It was the eighth spacewalk for Kimbrough, the fourth for Pesquet, and the fourth they have conducted together.

5. The remaining arrays are set to be installed by ISS astronauts later this year.

Horizons

Artificial hearts made from magnets and titanium could save many lives

The revolutionary design, which was first patched together using plumbing supplies, could begin human trials soon

Heart failure affects over 10 million people in the US and Europe every year and the outlook for patients is often bleak. Medication can only control the condition for so long and most patients require a heart transplant. If your heart slowly failing isn't scary enough, the number of donor hearts that become available each year is tiny compared to the number of people waiting for one. For some patients, their body size or blood type means the chances of finding a donor heart are virtually zero.

Attempts have been made to design artificial hearts since the 1950s, with little success. Many tests of artificial hearts over the years have involved seeing how many days – and it was often days – some poor animal could survive with one installed instead of its natural heart. The complex system of artificial pumps and valves – required to beat over 100,000 times a day and tens of millions of times a year – get worn out, meaning mechanical hearts can start to fail even more rapidly than the diseased hearts they replace.

The few artificial hearts that have been approved for human use are currently only ever used as a last resort, to buy a patient time before a real transplant. Patients have to wear cumbersome power boxes at all times, and wiring runs in and out of their chests, leading to infections.

But a completely new design, known as BiVACOR, could revolutionise the use of artificial hearts and the way heart failure is treated. Instead of trying to replicate the way a real heart pumps, the device uses a single spinning disc to drive blood to the lungs and body. With the high-tech rotary pump levitating between magnets, there's virtually zero mechanical wear. The lack of other moving parts means the rest of the heart can be made from ultra-robust titanium.

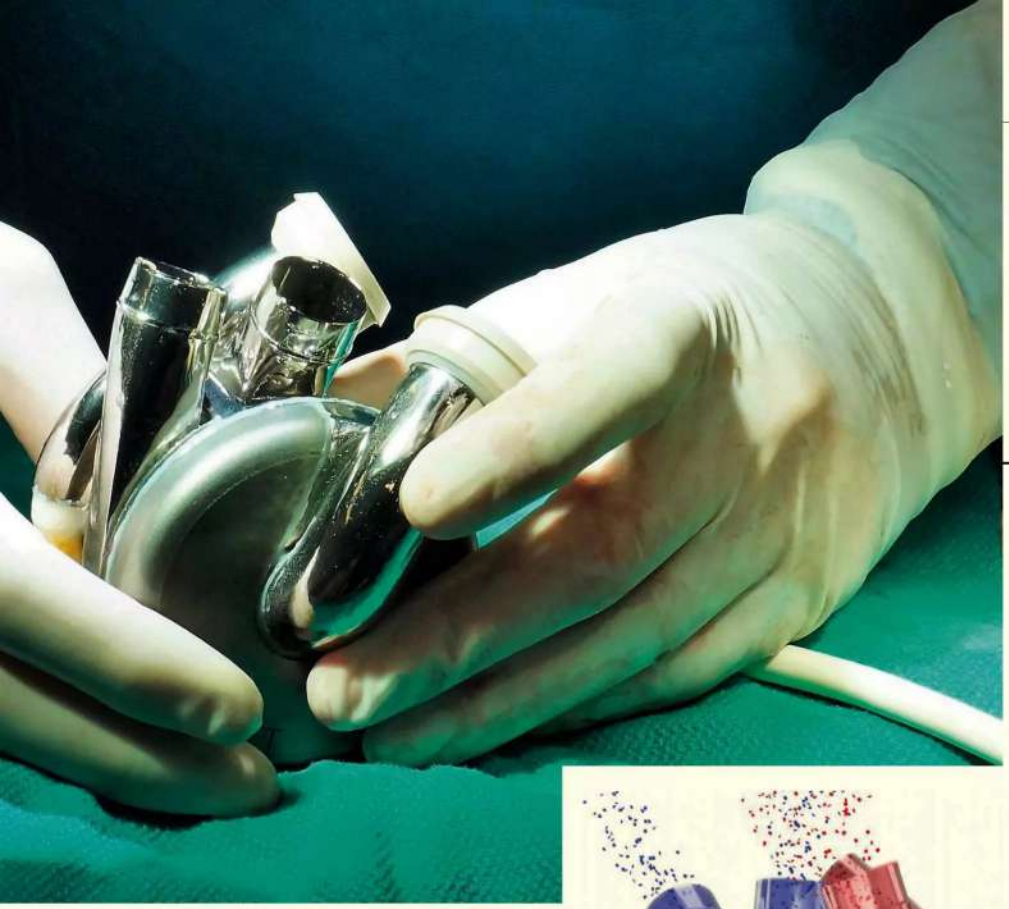
As well as its state-of-the-art levitating disc technology, the BiVACOR heart can adapt its output to the physiological demands of the patient (so it'll pump faster during exercise) and can be made small enough to fit into a child. It's also hoped that the device can one day be combined with wireless charging technology, meaning that the battery could be implanted into the patient, instead of carried externally.

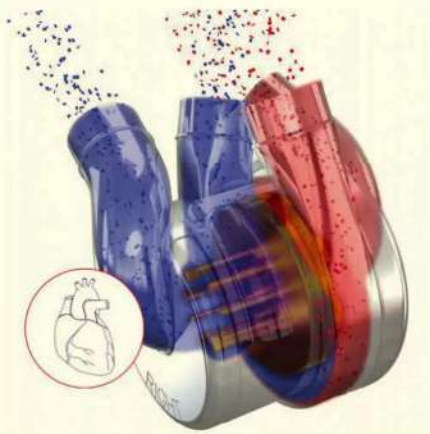
BiVACOR is the brainchild of Dr Daniel Timms, who began developing artificial hearts when his father Gary, a plumber, suffered a heart attack in 2001. When the problem of heart transplant shortages became clear to him, Timms – still a student at the time – started working on a prototype using 3D printing and plumbing equipment.

"We had no money to do anything like animal studies, that was just way

> **"The design's great promise is arguably that it's not at all like an actual human heart"**

BIVACOR X2





The spinning disc in the centre of the device is the only moving part in the new artificial heart

too expensive. So my dad and I built a circulation system that replicated the human body," said Timms, now chief executive of BiVACOR Inc. and an expert in cardiac transplant technology.

"We'd just go to Bunnings, our large hardware store here in Australia, and build up a circulation loop to test to see if it was providing good flow and pressure to the various areas of the artificial body that we created. Then we refined the devices from there."

Back in 2001, spinning disc technology was in its infancy, but it was being used in implants that help blood flow in damaged areas of the heart. Timms's idea was to take that technology and use it to design an entire heart from scratch.

"Effectively everyone had given up on making a complete, total artificial heart," he said. "Instead they were making these little devices that could be placed, say, in the left side only, and were just starting to use spinning disc technology. My approach was: 'Why don't you apply that to a total replacement heart?'"

THE 50-YEAR WAIT

The first artificial heart implantation was conducted in 1969 at the Texas Heart Institute, in Houston. When the patient survived for 64 hours without the heart he was born with, it was seen as a success; hopes were high that artificial heart transplants would become commonplace in the decades to come. But it simply hasn't happened. Over half a century later, cardiac doctors are seeing more patients with heart failure every year, but are still waiting for a device that can reliably do the job of the organ beating away constantly in our chests.

BiVACOR has once again raised hopes that artificial hearts could put an end to the fraught and often futile search for donor hearts. The new design has not only raised millions of dollars in funding, but has also has gained support from the Texas Heart Institute, which leads the world in cutting-edge cardiac healthcare.

According to Timms, the design's great promise is arguably that it's not at all like an actual human heart. "It's a bit like heavier-than-air flight. Mother Nature gave birds flapping wings with bones and tendons and muscles. When we tried to do that in the early days of flying it really didn't work very well. It wasn't until we stopped trying to emulate birds and developed propellers and engines that we got off the ground."

Since 2019, BiVACOR has been working with NASA, using their expertise in building ultra-reliable hardware for situations where failure means certain death. The device has been tested in a cow, which reportedly not only remained alive, but was also able to run on a treadmill, as well as other animals. And last year, doctors temporarily fitted BiVACOR devices into human patients undergoing heart transplant operations, as a first step towards human trials. Custom-made devices, tailored to the patients' anatomical dimensions, were fitted to see if they'd work, before real donor hearts were implanted.

The company is now working towards its first proper human trials. The plan is to implant the devices into patients who can't find a suitable heart donor, for three months, and monitor how they perform. Long term, it's hoped that BiVACOR hearts can replace the total function of the patients' hearts and offer hope to the millions of people who are waiting or are unsuitable for heart transplants. If successful, it will end one of the great challenges of biomedical engineering.

"I had no inclination that it would turn into what it's turned into now, none at all," said Timms. "It was just a crazy idea that I thought somebody else must have already had, or that might move the field along and then somebody would take it from there."

TOM IRELAND
Tom is a freelance science journalist, and editor of The Biologist, *the bi-monthly magazine of the Royal Society Of Biology.*

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Open your eyes anywhere on Earth and there is life: whether it's a pigeon or the invisible microorganisms coating every surface. But when the planet was born 4.5 billion years ago, it was sterile. How did the first life emerge?

The short answer is we don't know. If we did, we could reproduce it. Scientists could put the right chemicals in a sealed container under the correct conditions and when they opened it, they'd find living organisms. Nobody has ever done this.

But while we don't know exactly how life began, we have a lot of clues.

Let's start with the easiest bits: what is life made of and where did those components come from? Living organisms contain thousands of chemicals: like proteins and nucleic acids that carry our genetic information. These chemicals are complex, but we now know that their constituent parts form quite readily.

The first evidence of this was published in 1953 by a young chemist named Stanley Miller. He put water and three gases in a glass apparatus, mimicking the sea and air of the young Earth. Miller heated the water and electrically shocked the air to simulate

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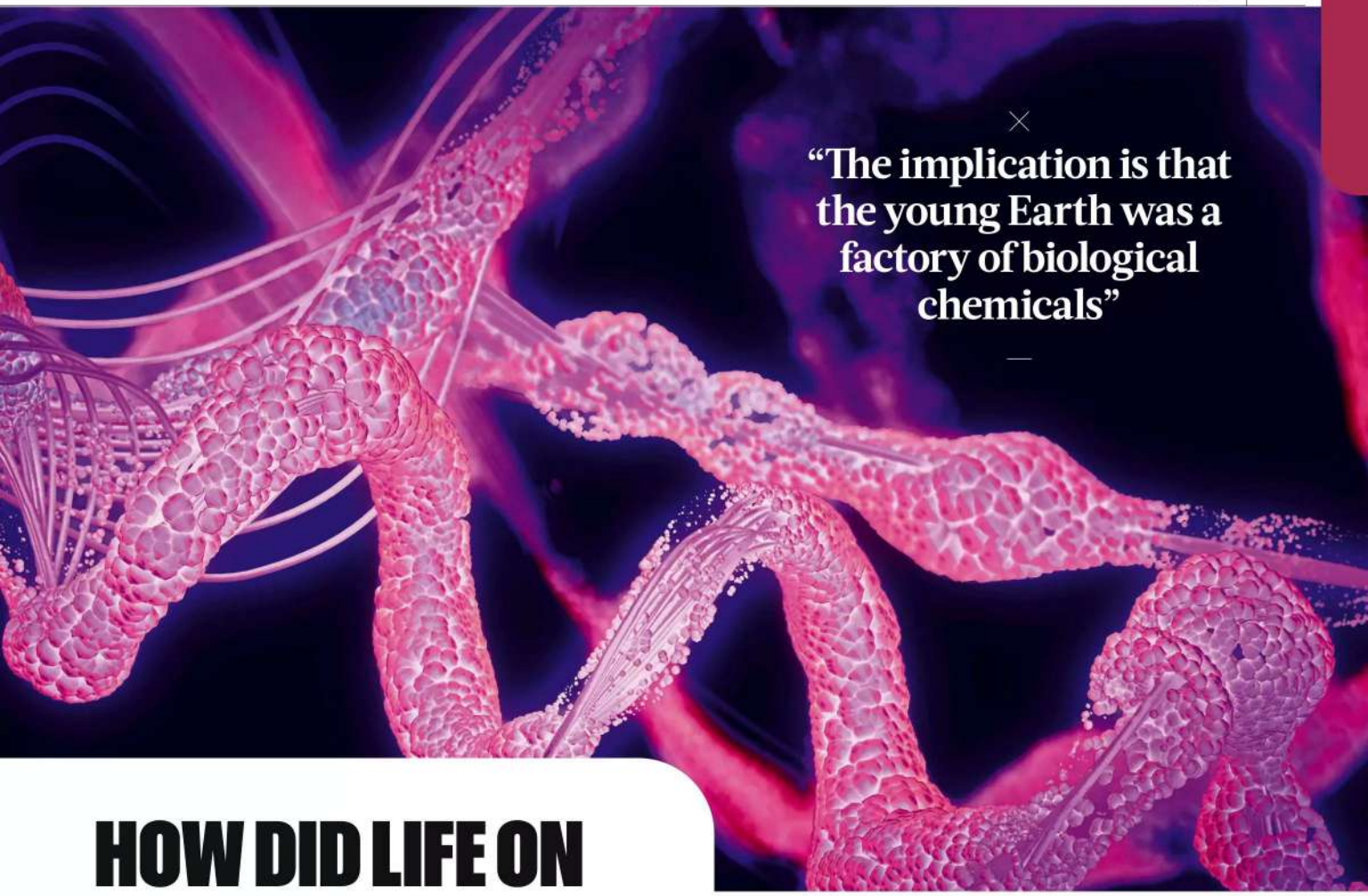


> "The implication is that the young Earth was a factory of biological chemicals"

HOW DID LIFE ON EARTH BEGIN?

Earth is unlike any other planet we know of by virtue of hosting life – and not just in a single form, life is present in a rich variety of species. But, as MICHAEL MARSHALL **explains, we still don't know what got it started**

ABOVE Life, as we know it, requires proteins, which despite being complex chemicals, form quite readily in nature

lightning. Within days, this setup produced an amino acid: a fragment of protein.

Since then, scientists have performed many similar studies. In research published in September 2020, researchers led by Sara Szymkuć (now president of start-up firm Allchemy Inc), compiled dozens of experiments. They created a 'map' showing how chemicals can be transformed one into another. Starting with just six everyday chemicals, such as water and methane, they could make tens of thousands of substances found in living organisms.

The implication is that the young Earth was a factory of biological chemicals. But having lots of these chemicals doesn't necessarily yield life, any more than a pile of bricks will automatically become a house.

This is where things get tricky, because we must think about what makes something alive. It boils down to three things. First, the organism has to keep itself together, often with an outer layer, the removal of which is immediately problematic. Second, it must feed itself. This involves complex chemical reactions. And third, life has to reproduce itself, which means it must have genes it can pass on.

CAN YOU HAVE ONE WITHOUT THE OTHERS?

The last 50 years of origin-of-life research were dominated by attempts to make one of these systems on its own: for instance, a genetic molecule that reproduced by copying itself. The other bits were assumed to come later.

Personally, I'm dubious about this approach. None of the three systems is alive by itself: they need each other. What's more, if Earth was doing such a good job of making all the chemicals of life, it may be that all three systems formed simultaneously in the same place. This would have happened more readily in a confined space, such as a deep-sea hydrothermal vent or a pool on land.

Exactly how life originated is still unclear, but what was once utterly mysterious now seems much less inexplicable. **SF**

SHOULD WE LOOK FOR ALIENS?

Even if all we learn is that we're alone, the search is worth the risk, argues LORD MARTIN REES. **Besides which, anyone we do end up finding probably knows about us already**

Are we alone?" is probably the question astronomers get asked most often by the general public. The search for extraterrestrial intelligence is surely worthwhile, despite the heavy odds against success, because the stakes are so high. That's why we should welcome Breakthrough Listen – a 10-year commitment by Russian-Israeli investor Yuri Milner to buy time on some of the world's best radio telescopes and develop instruments to scan the sky in a more comprehensive and sustained fashion.

But even if the search succeeded (and few of us would bet more than 1 per cent on this), it's unlikely that the 'signal' from aliens would be a decodable message. It would more likely constitute a by-product (or even a malfunction) of some super-complex machine far beyond our comprehension that could trace its lineage back to alien organic beings on a planet whose evolution might have had a head start of a billion years (or required a billion years less) relative to that on Earth.

It makes sense to first focus searches on Earth-like planets orbiting long-lived stars. But science-fiction authors remind us that there are more exotic alternatives. In particular, the habit of referring to ET as an 'alien civilisation' may be too restrictive. A 'civilisation' connotes a society of individuals: in contrast, ET might be a single, integrated intelligence. Even if signals were being transmitted, we may not recognise them as artificial because we may not know how to decode them. A radio engineer familiar only with amplitude-modulation might have a hard time decoding modern wireless communications.

"Advanced aliens would already know that we're here and could be giving us special attention"

WATCHING AND WAITING

I find it hard to share the worries some express about transmitting any signals that would reveal our presence: advanced aliens would know already that we're here and could be giving us special attention because we're clearly undergoing a transition from a technological civilisation of flesh-and-blood creatures to a complex near-immortal cyborg or robotic entity.

Perhaps the Galaxy already teems with advanced life and our descendants will 'plug in' to a galactic community as 'junior members'. On the other hand, Earth's intricate biosphere may be unique and the searches may fail. This would disappoint the searchers. But it would have an upside. Humans could then be less cosmically modest. The tiny planet we find ourselves on – this pale blue dot floating in space – could be the most important place in the entire cosmos. Either way, our cosmic habitat seems 'tuned' to be an abode for life. Even if we are alone in the Universe, we may not be the culmination of this 'drive' towards complexity and consciousness.

Finally, there are two familiar maxims that pertain to this quest. First 'extraordinary claims will require extraordinary evidence' and second 'absence of evidence isn't evidence of absence'. **SF**

ALAMY

There are potentially many places where life could be hiding in the Universe. But does any of it want to hear from us?

HOW LONG SHOULD WE EXTEND HUMAN LIFE?

We're all getting older. But how long should we be able to keep getting older for? HAYLEY BENNETT **looks into what happens if human lifespans continue to lengthen**

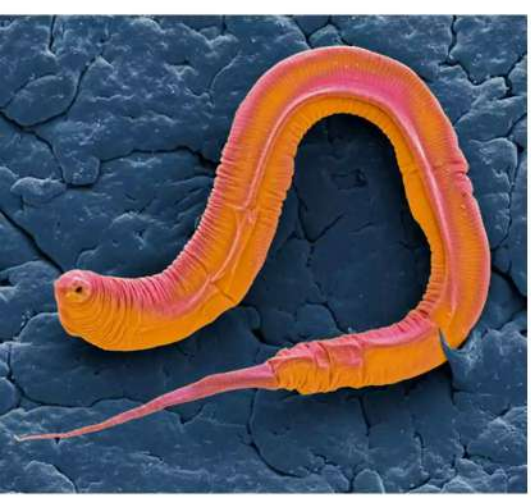
In 2020, US and Chinese scientists found a way to enable worms to live five times longer than normal by manipulating their genes. Worms are often used in ageing research since we've inherited some of the same genetic circuitry during evolution. It's suggested that targeting some of these conserved genes using drugs could be a way to extend the human lifespan. But since worms only live for a few weeks, extrapolating the US and Chinese scientists' success to humans could be foolhardy. In short, we can't expect to live to 500.

But let's not be greedy. We already live far longer than our hunter-gatherer ancestors, who invariably snuffed it before the age of 40. Should we, though, stop considering life as something that comes to its natural conclusion at 73 (today's average global life expectancy) and devote more of our time to curing old age?

MORE PEOPLE, MORE STRESS

One argument against extending human life beyond the norm is that it would lead to overpopulation, requiring more resources, while creating more waste, carbon emissions and pollution on a planet we've already stressed to breaking point.

That's not usually what happens when people start living longer, though. Instead, birth rates tend to drop as people have fewer children and have them later in life. We know this



ABOVE It's estimated that a third of today's four-year-olds will live to celebrate their centenary

LEFT By altering genes in *Caenorhabditis elegans* roundworms, scientists have been able to increase their lives by up to five times their usual length

GETTY IMAGES, ALAMY ILLUSTRATION: MERINO/ARONSON/BOJANOVA/FEYHL-BUSKA/WONG/ZHANG/GIOVANNELLI

IS THERE ANYWHERE ON EARTH LIFE DOESN'T EXIST?

The 'ideal' conditions for life don't have to be ideal for us, because it keeps springing up in the sort of places we least expect

"Life finds a way," said Dr Ian Malcolm, Jeff Goldblum's character in the original *Jurassic Park* movie. The statement is true, not only for the chaotic events that unfold in the film, but also for occurrences away from the silver screen, in the real world. Life seems to be capable of establishing a presence in every corner of the planet, no matter how hostile the conditions appear to be. Whether the immediate environment is blisteringly hot or bitingly cold, corrosively acidic, crushingly high pressure or radioactive, life adapts to tolerate it. Provided there's liquid water, however little of it there may be, life springs up. That life comes in many varieties of microorganism, but if it can tolerate these sorts of extreme conditions it's classed as an extremophile. On Earth, extremophiles have been found in all of the following environments...

> "The world's longest-lived nation, Japan, has an average life expectancy of 84"

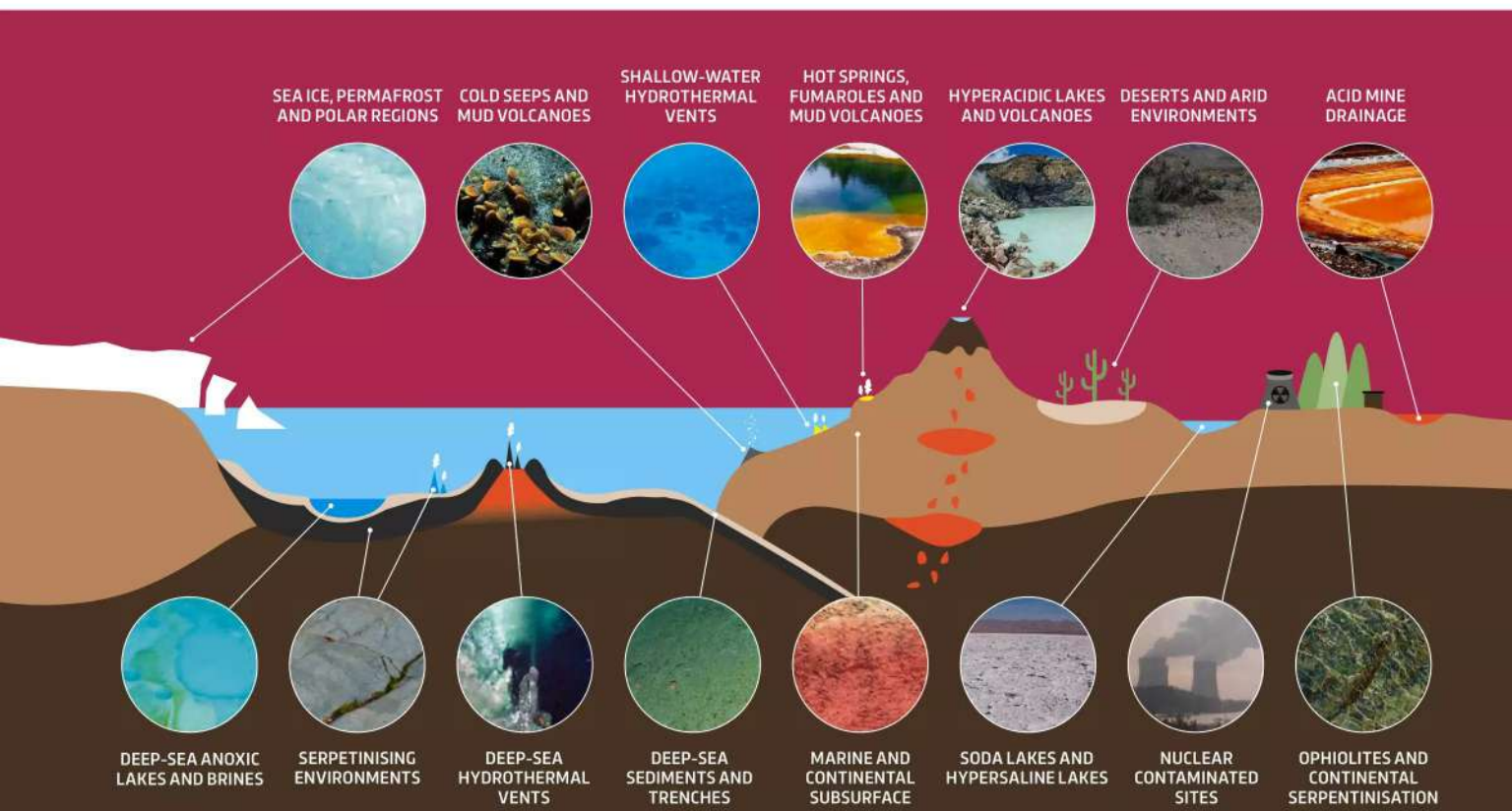
because it's already been happening for several decades as healthcare has improved. So even though the global population is growing, it's not growing as fast as it once was and in many richer countries, across Europe for example, populations are plateauing or shrinking as the birth rate (the average number of children each woman has) drops below two. The world's longest-lived nation, Japan, has an average life expectancy of 84 and a birth rate close to one, down from over two in the 1960s when life expectancy was below 70.

So provided people had fewer children, perhaps we could all live a little bit longer – maybe as long as people in Japan. In fact, some of today's four-year-olds can already expect a much better innings. In the UK, around a third are predicted to see their 100th birthday due to a trend towards living longer. Whether those extra years are desirable is another matter though, given there's no indication they would be healthy ones – studies from countries where life expectancy has increased have shown mixed results.

Meanwhile, the gulf between life expectancy in richer and poorer countries leads us to suspect that life-extending drugs and technologies will take longer to reach the less-developed nations.

Today, people in some African countries die on average two or three decades before the Japanese. So given the disparities that already exist, is it ethical to have more people living longer in richer countries, where we consume more resources?

If we were going to be fair about it, our first aim should be to increase life expectancy in Africa and the rest of the less-developed parts of the world, and ensure that a longer life doesn't come at the expense of healthy, happy life, right up to the end. **SF**

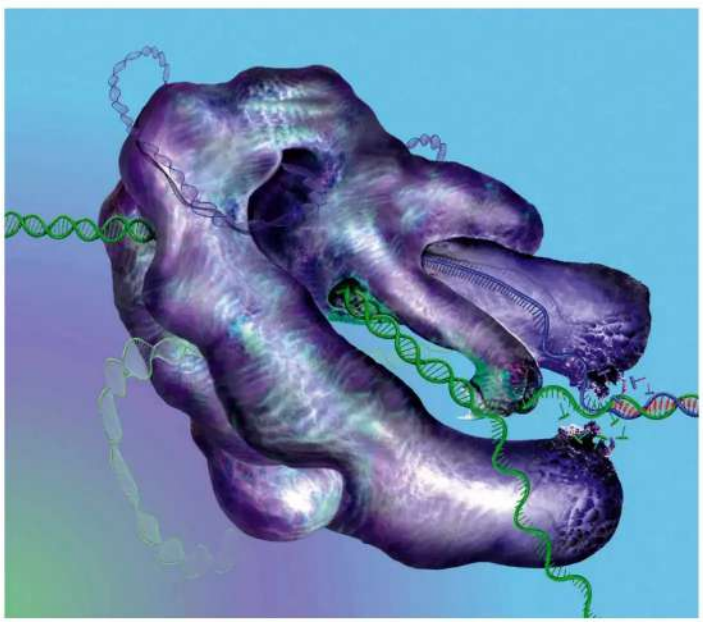

SEA ICE, PERMAFROST AND POLAR REGIONS
COLD SEEPS AND MUD VOLCANOES
SHALLOW-WATER HYDROTHERMAL VENTS
HOT SPRINGS, FUMAROLES AND MUD VOLCANOES
HYPERACIDIC LAKES AND VOLCANOES
DESERTS AND ARID ENVIRONMENTS
ACID MINE DRAINAGE
DEEP-SEA ANOXIC LAKES AND BRINES
SERPETINISING ENVIRONMENTS
DEEP-SEA HYDROTHERMAL VENTS
DEEP-SEA SEDIMENTS AND TRENCHES
MARINE AND CONTINENTAL SUBSURFACE
SODA LAKES AND HYPERSALINE LAKES
NUCLEAR CONTAMINATED SITES
OPHIOLITES AND CONTINENTAL SERPENTINISATION

SHOULD WE EDIT THE NATURAL WORLD?

A process that began centuries ago with selective breeding has developed into genetic modification. HAYLEY BENNETT **explores the consequences of using these controversial tools**

Back in the 1990s, we debated the risks and benefits of genetically modified (GM) crops. Some found the idea of eating 'non-natural' foods unsavoury, while others saw the merits of crops with increased yields and resistance to pests, drought and disease. Today, as pressures on farming intensify under climate change, we're seeing a new debate. The difference now is that scientists have better tools for editing genomes and we're not just talking about using them in crops.

Understanding how the old and the new tools differ is key to deciding whether you believe they should be used. The traditional technique of introducing foreign DNA to create transgenic organisms – as in insect-resistant corn, which contains genetic



ABOVE LEFT A biologist collects DNA samples from a barley plant in the hope of breeding hybrids more suited to future environmental conditions

ABOVE CRISPR enables scientists to target, cut and modify specific sections of DNA

GETTY IMAGES X2

> "Similar edits can be made by mutating DNA with chemicals or radiation and there are already thousands of varieties of plant species containing such changes on the market"

material from bacteria – is slower, more expensive and less accurate than modern gene-editing techniques. Gene editing today usually means making precise changes using CRISPR, a bacterial DNA-cutting system adopted by scientists. It works within the code of an existing genome rather than importing code from elsewhere. But if you value only what's completely natural in the natural world, you may not be comfortable with either approach.

Similar edits can be made by mutating DNA with chemicals or radiation and there are already thousands of varieties of plant species containing such changes on the market. Under EU law, though, gene-edited organisms are treated like traditional GM organisms and subject to more stringent regulations. Many scientists find these too restrictive. In a 2021 article, Columbia University's Dr Sarah Garland argues that the EU won't have the "luxury" of being able to ban gene editing for much longer – it'll be indispensable in creating food crops that are more resilient to changing conditions.

CHANGING VIEWS

Beyond farmed species, there are difficult decisions to be made about the balance of risks and benefits for the natural world. Should we, for example, edit the genomes of corals to help them withstand ocean temperature and acidity changes caused by climate change? Or edit the genomes of trees to help them fight fungal diseases? What's confusing is that some of the modifications we're now considering could have been achieved years ago through traditional methods, so our views depend on what we think about the safety of new editing technologies, but also how desperate we are to address environmental degradation.

A recent study by environmental policy expert Jesse Reynolds suggests that the conservation potential of gene-editing technologies may be proving persuasive as environmentalists seem less resistant than they once were to such technologies. The International Union for Conservation of Nature is due to vote this year on a set of guiding principles that covers gene drives – self-replicating edits based on CRISPR technology that can spread quickly through generations. Here, the debate gets tricky, as gene drives could affect entire species. They could be used to obliterate whole populations of disease-causing organisms, such as the mosquitoes that carry malaria. Hopefully, we'll also see local communities affected by these organisms getting involved in the debate. **SF**

ARE WE LIVING IN A SIMULATION?

Could computers ever become sophisticated enough to build a convincing facsimile of the real world? What if they already have and we're living in that facsimile? DR PETER BENTLEY looks into the likelihood of us being trapped in the Matrix

Today's computers are incredible. Nearly 50 years ago, we had *Pong*, one of the first computer games, which played 'tennis' using moving blocks on each side of the screen. Today we have photo-realistic virtual worlds filled with computer-generated characters that all seem to move and behave as they should.

The advancement of computers is said to follow Moore's Law, named after Gordon Moore, one of the founders of Intel. In the 1960s, Moore saw the rate of progress and predicted that the number of transistors on a chip would double every two years. By the mid 1970s there were 10,000 transistors on a chip. By 1986 it was more than a million. And by 2020 we had 2.6 trillion.

Because of Moore's Law, computer power has been doubling about every 20 months. If our technology keeps improving at this rate, what will we have in another 50 years? Or 100? Or 1,000? Will our futuristic quantum-scale computer processors be so powerful that the virtual worlds they create contain complexity as rich as we see around us? Will there be virtual worlds populated by virtual people inventing their own games and wondering where it'll all end? Or has this already happened? Are we living in a simulation created by computer programmers who, technologically, are a few thousand years ahead of us?

> "Simulating this level of complexity needs resources, knowledge and time"

Computers with this kind of processing power could also have other abilities. If they could simulate a universe, recent progress in AI research seems to indicate that they would have no problem simulating a brain – even a super-intelligent brain [although some, such as Dr Lisa Feldman Barrett, would disagree, see p66]. Such a super-human AI would be like a god to us and what it chose to do might be beyond our understanding or control.

A COMPLEX PROBLEM

Such fears of a 'technological singularity', where progress becomes uncontrollable and irreversible, ignore the wider and very real world that we live in, and the difficulty of the problem.

It took 13.8 billion years to make the Universe, the observable part of which comprises 10^{80} atoms. Simulating this level of complexity needs resources, knowledge and time. Our world has limited resources. And even if we had the computers and the knowhow, the simulations would take billions of years of computing time to run. Why would we want to do that? We're more likely to invent artificial gravity or teleportation than simulate entire universes or super-intelligent brains in the next few hundred years. And we're much more likely to wipe ourselves out before then through environmental disasters.

Simulated or not, it doesn't matter – Earth is the only home we have. Perhaps we should focus on the technologies that are already threatening life today, rather than worrying too much about implausible science-fiction scenarios of the distant future. Otherwise, there'll be no future to worry about. **SF**

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QUICKFIRE

WHY DOES ALL LIFE NEED WATER?

There are many reasons, but they all hinge on water's unique chemical properties. For the thousands of chemical reactions going on in our cells to happen quickly and efficiently, the molecules need to be dissolved in something. Water is so good at dissolving substances that it's known as the 'universal solvent'. Other substances have similar dissolving power to water, but they don't have its chemical stability and its ability to neutralise strong acids and bases.

HOW MUCH BIOMASS ON EARTH IS HUMAN?

Grab all of humanity, grind it down and weigh just the carbon and you'd be able to measure our collective biomass: an estimated 60 million tonnes. But this only makes up 0.01 per cent of Earth's total carbon (546 billion tonnes). To put that in perspective, the planet's viruses have a total biomass three times larger – and bacteria over 1,100 times. The vast majority of Earth's biomass consists of plants (82.4 per cent), with animals making up 0.4 per cent – and humans comprising only 2.5 per cent of that!

ARE MY CELLS YOUNGER THAN ME?

Ignore the candles on your last birthday cake: your body is years younger than you. In fact, by applying carbon dating techniques to human DNA, scientists have determined that most cells in your body are less than 10 years old. But the lifespan of your cells can vary massively: while skin cells only last for 14 days before dying, skeletal muscle lives for around 15 years.

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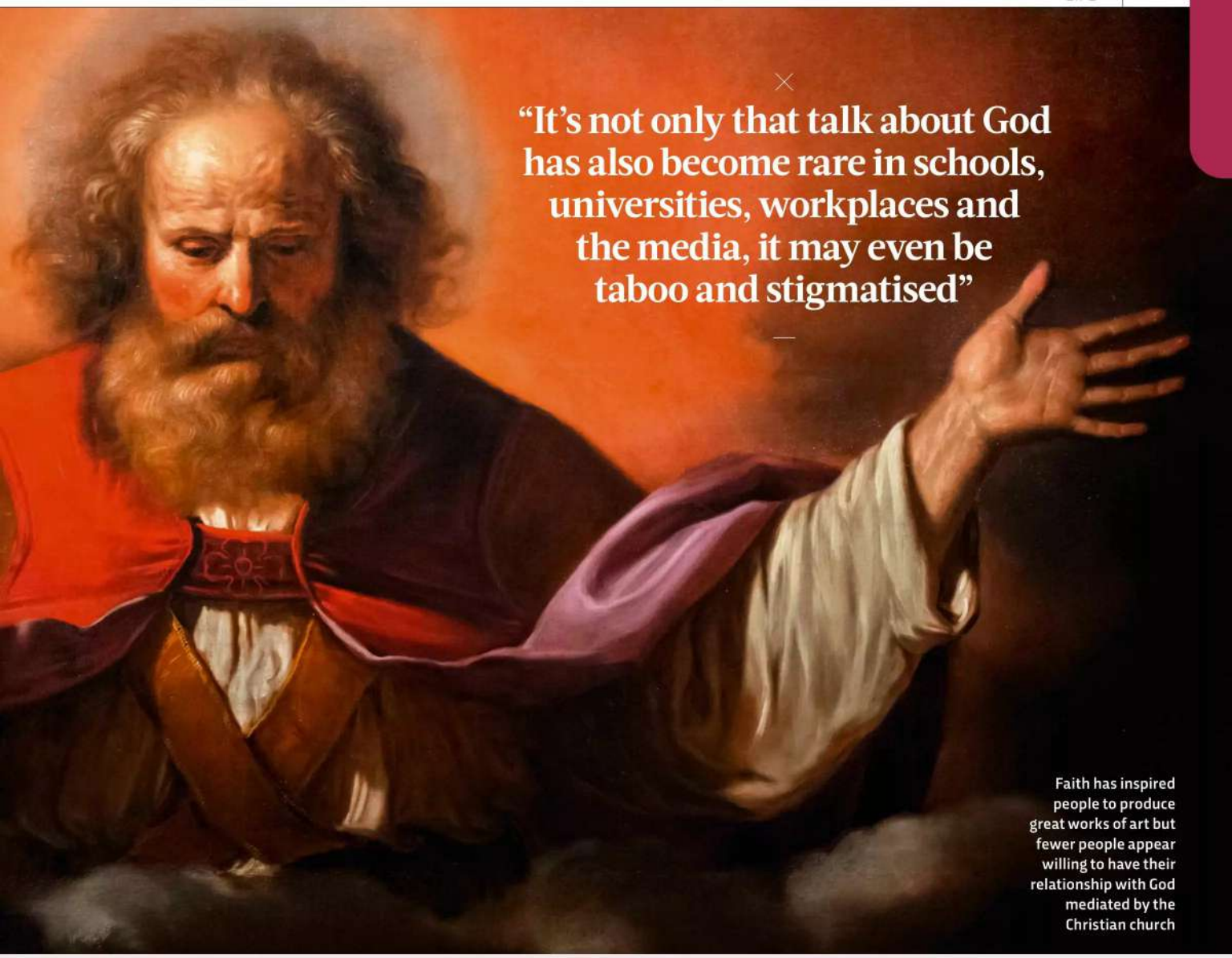
WHY ARE FEWER PEOPLE BELIEVING IN GOD?

Is the Divine losing its draw? PROF LINDA WOODHEAD **looks into whether we're a faithful flock that's temporarily strayed, or if we're no longer willing to take a leap of faith**

Britain is one of the most secular countries in the world. Belief in God has been declining, along with other indicators of religion, since polling began. In 1961, when a question about God was included in a survey by the National Opinion Polls, 91 per cent of Britons expressed belief. By 2018, according to the British Social Attitudes survey, that had fallen to 55 per cent of the population, with 26 per cent affirming that they've never believed.

Nevertheless, these figures show that a majority of Britons still believe, whether confidently or tentatively. Belief in God has declined less sharply than other aspects of religion, like belonging to a church and taking part in its rituals. Organised religion has been losing followers quicker than God!



> "It's not only that talk about God has also become rare in schools, universities, workplaces and the media, it may even be taboo and stigmatised"

Faith has inspired people to produce great works of art but fewer people appear willing to have their relationship with God mediated by the Christian church

This suggests, contrary to a common view, that losing faith in God is not the main reason people leave organised religion. It's just as often the other way around – people who don't belong to a religion are less likely to believe in God. If your family isn't religious and you're raised without any meaningful contact with a religious group, you're less likely to believe.

So the main reason for declining belief is that fewer people are enculturated and socialised into belief. They're not brought up with the 'plausibility structures' (the wider sociocultural norms and frameworks of meaning) that are found in more religious societies. It's not only that talk about God has also become rare in schools, universities, workplaces and the media, it may even be taboo and stigmatised. People who believe in God often worry about being viewed as weird or unintelligent. Confident atheists reinforce these negative views.

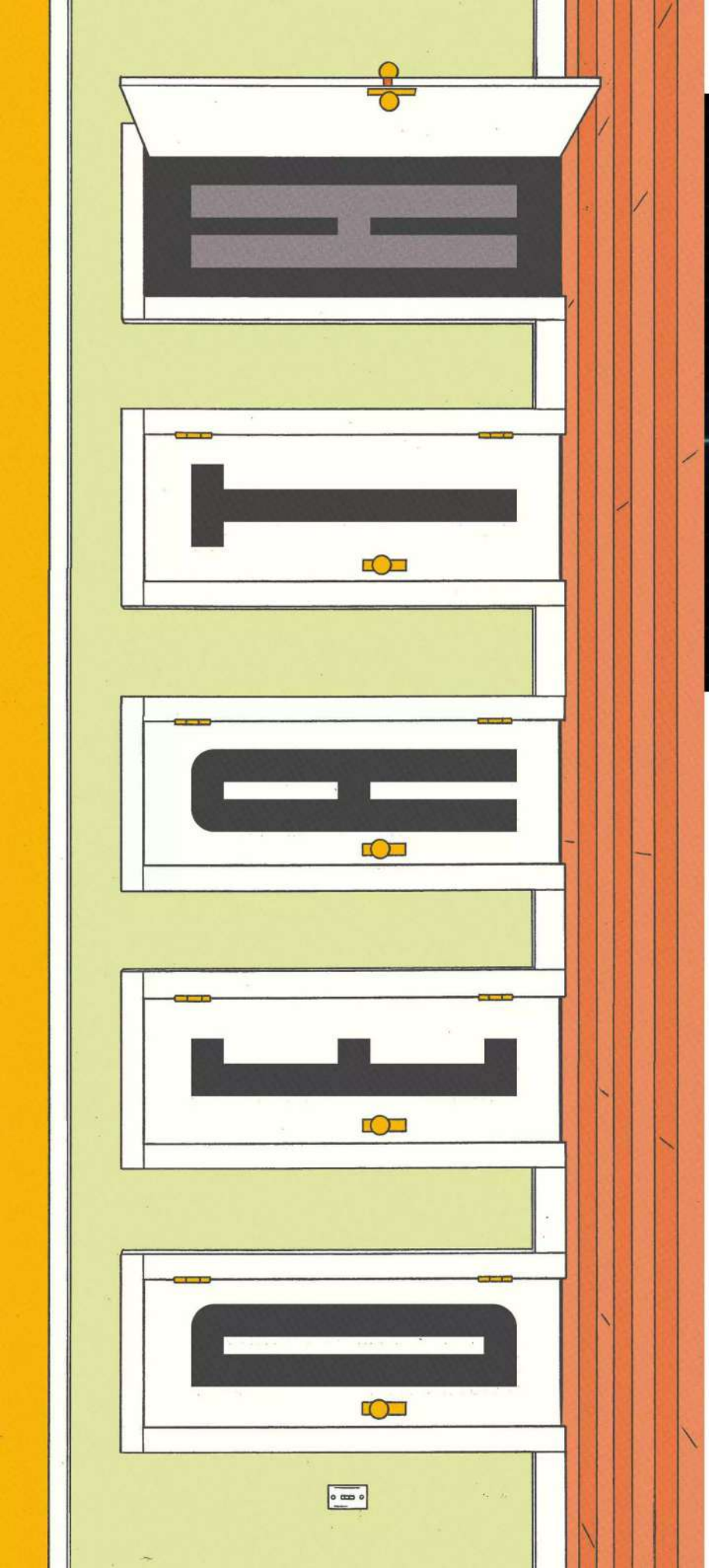
There are philosophical objections to belief as well, like the so-called 'problem of evil', which asks how an omnipotent and benevolent God can allow evil and suffering. This isn't an issue for those who believe there are many gods and spirits (who are not all-good or all-powerful), but it is a problem for some forms of monotheism.

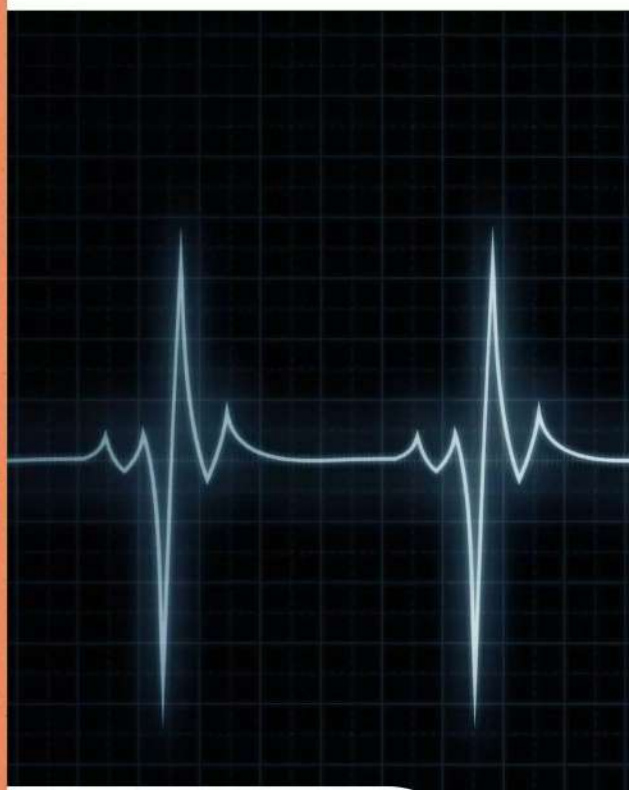
SPIRITUAL PLURALISM

In Britain today, confident atheists and confident theists remain minorities in society. They may be the most vocal, but they're outnumbered by people who are agnostic, or keep an open mind, or believe in unseen forces and powers, or God and gods – or who just think it likely that there's 'something more out there'.

Although it's likely that the downwards trend in belief will continue, it's not inevitable. Belief in God isn't a static thing, and the way that people experience and understand God changes. It's true that Christian plausibility structures for a certain kind of monotheism have been declining. But increased religious pluralism, tolerance and the way that new forms of spirituality have entered into mainstream culture offer new kinds of plausibility and new ways of encountering the divine.

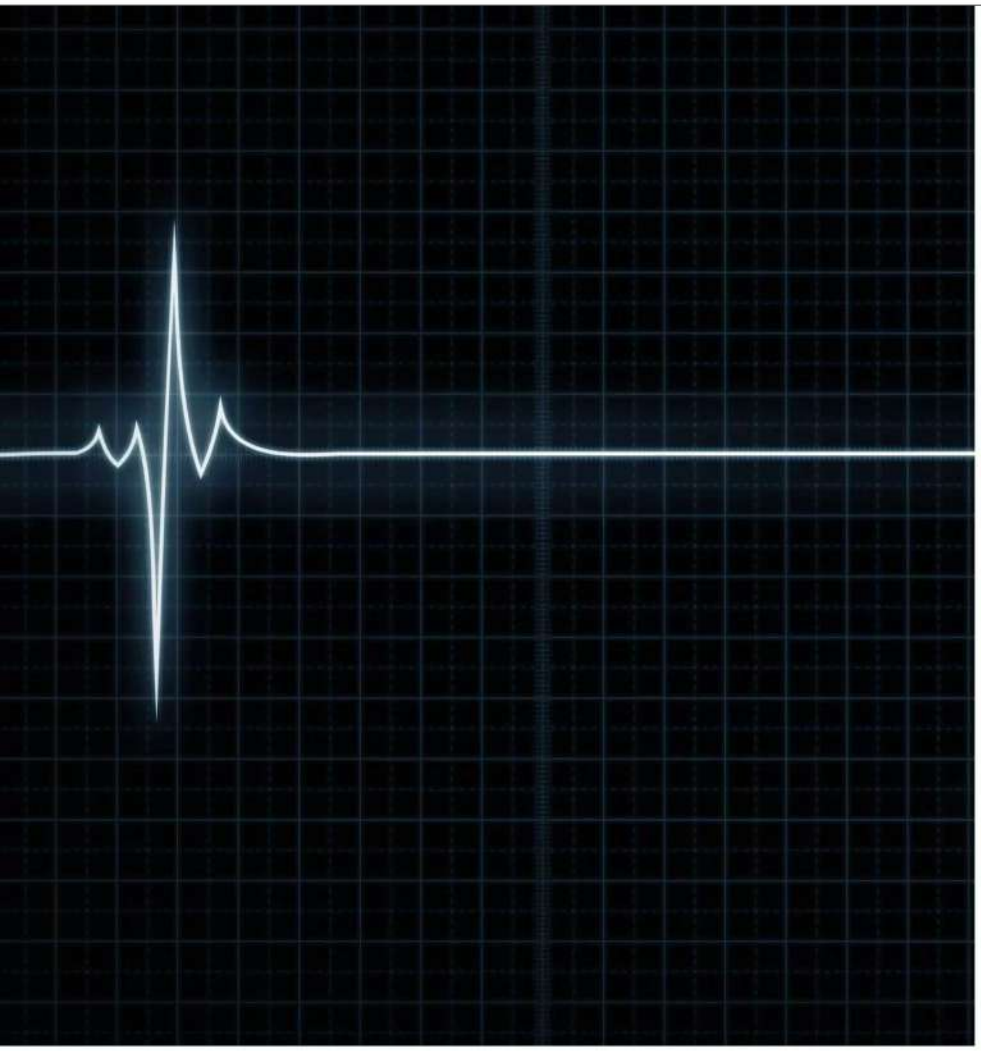
The most likely scenario for belief in Britain is increased diversity, with contention between a range of different religious, non-religious and atheistic approaches. **SF**





WHAT HAPPENS WHEN WE DIE?

While we don't know if anything happens afterwards, we do know exactly what happens in the moments leading up the end. DR KATHRYN MANNIX **leads you through the last few steps on your body's journey**



LEFT Absent of other factors, fatigue leads to sleep, which gives way to unconsciousness, until, eventually, the person dies

Like giving birth, dying is a bodily process with stages and recognisable progression. Also like birth, the speed of the process can vary from person to person. Medical support is sometimes needed to make dying (or giving birth) as safe and comfortable as possible.

As dying approaches, most people lose interest in eating and drinking. This is normal: spoonfuls of 'tastes for pleasure' may still be welcome when meals have become too much to manage. Dying people consistently lack energy. Many of us have experienced profound weariness caused by illness: the 'can't get out of bed' state of severe flu, or overwhelming tiredness as we recover from surgery. Sleep usually recharges our energy and can be part of recovery but, at the end of life, sleep gradually makes less impact as the body winds down towards dying.

A dying person spends progressively less time awake. What looks like sleep, though, gradually becomes something else: dipping into unconsciousness for increasing periods. On waking, people report having slept peacefully, with no sense of having been unconscious. If the dying person is relying on regular medications to keep any symptoms at bay, then now is the time to switch to medications that don't require the person to be awake to swallow them. Skin patches, syringe pumps, or even suppositories can be used. It's important to know that unconsciousness isn't usually caused by the medications, but by the dying process itself.

"Eventually breathing slows and becomes very shallow; there are pauses and, finally, breathing ceases"

THE FINAL MOMENTS

As dying progresses the heart beats less strongly, blood pressure falls, skin cools down and nails become dusky. Internal organs function less as blood pressure drops. There may be periods of restlessness or moments of confusion, or just gradually deepening unconsciousness.

We have no proven way to investigate what people experience during dying. Recent research shows that, even close to death, the unconscious brain responds to noises in the room. We don't know how much sense music or voices make to a dying person, however.

Unconscious people's breathing follows automatic patterns generated by the respiratory centre in the brain stem. Because they're unaware of their mouth and throat, dying people may breathe heavily, noisily or through saliva in the back of their throat, yet without apparent distress. Breathing moves from deep to shallow and from fast to slow in repeating cycles; eventually breathing slows and becomes very shallow; there are pauses; and, finally, breathing ceases. A few minutes later, the heart will stop beating as it runs out of oxygen.

Knowing the pattern of ordinary dying and recognising its stages, helps companions to understand what they're witnessing, to feel less afraid of unlikely complications and to have the confidence to send for help if medical attention is needed to address symptoms and so to enable 'safe' dying. You can find out more by watching the BBC's short film on dying at **bit.ly/dyingisnotsobad SF**

GETTY IMAGES

QUICKFIRE

DO THE DEAD OUTNUMBER THE LIVING?

For most of our history there's no population data, but statisticians can make estimations based on birth rates and life expectancies over time. According to the Population Reference Bureau, Earth's been home to about 117 billion people. So today's 7.8 billion equates to just 7 per cent of the total.

CAN YOU DIE OF A BROKEN HEART?

Yes, broken heart syndrome – or Takotsubo syndrome (TTS) – is a real but rare condition where the heart experiences acute and sudden failure. Its exact cause isn't wholly understood, but research indicates stress-associated metabolic activity in the brain could lead to a greater risk of developing TTS. This suggests that not only can TTS be caused by the death of a loved one, but more common stressors such as a bone break or a colonoscopy too.

CAN WE 'FREEZE OUT' DEATH?

Alive, your body has a core temperature between 36.5 and 37.5°C. Anything below this and it enters a state of hypothermia, in which your metabolism slows and organs eventually fail. But hypothermia also reduces the brain's need for oxygen. And if the body is cooled fast enough, toxic chemicals don't accumulate around your heart. Hence, some medics use hypothermia to save lives, chilling stroke and heart attack patients for 12 to 24 hours, before warming them slowly, once they're stable.

CAN WE CURE OLD AGE?

Do you want to live forever? Are you sure? Because while you might be up for it, your body isn't. But there might be things we can do about that, says JULES HOWARD

Good news! Through vaccines, healthy diets and a great swathe of medical innovations, human lifespans have roughly doubled in the last century or so, from an average of 35 years in 1900 to an average of more than 70 years today.

But, wait… you want more?

Perhaps understandably, you won't find yourself alone in seeking to stretch your life out that bit further. In fact, one unrelenting ideal, frequently chased by Silicon Valley companies, sees us running upstairs well into our 90s and has our brains being as fresh as a child's into the 12th decade of life. It also envisions a future where USB-enabled brains in jars live to see the extinction of the Sun.

MAKE ROOM FOR THE NEW STOCK

The truth is that ideas such as these may one day be as dated as the mythical notion of an elixir of life. Cells, on the whole, are not built to last. Animal bodies (and the genes that reside in them) are built to procreate, to multiply, to replicate. Evolution will always favour death, because the bodies that hang around too long without making more become grist to the mill – eaten by predators, outmanoeuvred by competitors, riddled with parasites or simply victims of an endless rain of lethal solar radiation. In this way, to a degree, ageing is baked into our DNA.

This evolutionary contract we have with death means that even if we eradicated all human diseases, 100 years into advanced age our bodies would begin to show the same frailty. There would be the same struggle to recover from everyday stresses, and the same "where did I put the keys?" moments. In fact, a study published in the journal *Nature* this May confirms it.

GETTY IMAGES X2, ALAMY

Based on data from 500,000 volunteers from Russia, USA and the UK, scientists now estimate that the human body could not withstand much more than 120 years and certainly no more than 150 years, before the accumulation of DNA damage that is ageing's central cause builds to a level that brings about what one scientist calls "the ultimate lingering death".

Could other animals offer some secrets to extended life? The answer is an assertive yes, according to many scientists.

Among the cast of extraordinary agers in the natural world are the lobsters that have evolved an enzyme that protects the ends of DNA strands, the bits most easily damaged during replication; the lowly roundworms, who seem to have something akin to a slow-motion ageing setting to get them through times when food is scarce; and the naked mole rats, who appear to have a knack for limiting the damage caused by problematic oxygen atoms, known as free radicals, that have a habit of going rogue in animal cells and destroying DNA (whereas most rodents live two or three years, the naked mole rat manages to live 30).

ABOVE At 118 years old, Kane Tanaka is the world's oldest verified living person. She was born in Fukuoka, Japan in 1903

LEFT Naked mole rats, with their 30-year lifespans, appear to age differently to other rodents

Could these animals expose their genetic secrets to us? Might we one day 'bio-hack' their DNA codes and insert these anti-ageing tricks into our own genomes? The truth is that it's possible. It might not be in decade or a century, but it's fair to say that, one day, we really might live far healthier lives for longer.

HOW LONG IS LONG ENOUGH?

Yet, for all this ingenuity and scientific well-wishing, my gut tells me the same question will persist should we have success in extending our lives further. "How can we live for even longer?" future generations that live to 200 may well ask, stirring the same philosophical pot that has defined our species for millennia.

And so, for me, the whole idea of 'curing' ageing is something of a fallacy. You might as well try and cure childhood or middle-age or birth. There will always be death. So, celebrate the fact that no generation before yours has been able to live a life so long. Life is short, but it was once far shorter, so seek to cure your fear of death, rather than death itself. **SF**

GETTY IMAGES

ARE WE THINKING ABOUT DEATH WRONG IN THE WEST?

Everyone who's alive now – you, your friends, your family – one day won't be. It's an unavoidable fact and yet we often go to great lengths to avoid acknowledging it. JULES HOWARD **explains why that might be a mistake**

According to data from the company Statista, just 11 per cent of us consider death in our daily lives. Most of us are clearly busy with the subject of life, perhaps only considering the subject three or four times a year. We in the West are, in the words of one philosopher, masters of "burying existential anxieties under a mound of French fries". But that's understandable, right? Death is horrible. We live. We die. And then it ends. What possible reason could there be for thinking about death more? Plus, French fries are delicious.

According to some scientists however, there are advantages to thinking about death more. Psychologists, in particular, point to a number of studies that suggest that thinking about death ('mortality salience') can raise people's self-worth, encourage them to be less money-orientated and even make them funnier. Buoyed by research like this there are social movements, such as so-called Death Cafés and the Death Salon collective, that provide space for people to meet and talk openly about death.

FACING UP TO THE INEVITABLE

In many ways, groups like these mirror Eastern philosophies, which have urged people to consider death and the frailty of human existence, for centuries.

Buddha, for instance, was an advocator of 'corpse meditation' where dead bodies are observed in various states of decay. "This body, too," one text states… "such is its nature, such is its future, such its unavoidable fate."

And the very notion of 'yin and yang' – the dualistic idea of 'light and dark' and 'fire and water' and 'life and death' – appears to inspire in non-Western audiences a greater appreciation of everyday things than in Western audiences.

So, are we in the West thinking about death wrong? I would argue, no. Because there's no 'wrong' way to do it. But we could certainly do with thinking about it more. Not loads more, just as much as each of us feels is right. In so doing, our perspective on day-to-day events might be imperceptibly improved. After all, to those of us that know that life is impermanent, the French fries have never tasted so good. **SF**

> "According to some scientists however, there could be advantages to thinking about death more"

HOW CAN WE DEAL WITH ALL THE DEAD?

More people die every day, but our graveyards aren't getting any bigger. So what happens when we inevitably start running out of places to put the bodies? JULES HOWARD **takes you through the options**

Anthropologists laud the common human practice of burying our dead as one of the hallmark traits that set us apart from other apes. Town-planners, on the other hand, must lament it. For these individuals face an impossible dilemma: most of the graveyards and cemeteries are nearly full, yet people have a nasty habit of continuing to die.

In the UK, partly because of the surge in town- and city-living, the problem of where to put all these bodies is a particularly thorny one. According to research published earlier this year, a quarter of council-owned cemeteries will be full to capacity in 10 years and one-in-six will be full within five.

How might we avoid the nightmarish situation? What might we do to avoid a serious crisis in the way that we manage our dead? Recycling graves is one obvious option. The graves of people who died 150 years ago tend not to get many visitors, so those that have recently passed can be laid to rest on top with very little fuss. The pros to recycling graves in this way are that it's cheaper and it means, potentially, that families can be buried in the same graveyards – a final request that is increasingly difficult to honour. The practice is commonplace in Germany.

ABOVE Niches, like these in Barcelona's Poblenou Cemetery, hold cremated ashes in urns, but others in Spain and Greece contain people's bodies until their remains can be moved to a communal grave

In Greece and Spain, a similar approach is to rent a 'niche' – an above-ground crypt where bodies are laid to rest and decompose naturally, before the remains are removed and put in a communal grave. Again, the benefit of this practice is that it increases the 'throughflow' of burials, making for a more efficient use of space.

When it comes to dealing with the dead, perhaps the best space-saving option is cremation, the UK's preferred post-life practice. According to 2019 data, 78 per cent of British funerals involved cremations, making it the go-to option for many. Yet cremation has its downsides. Environmentally, there's the 536kg

"There's 536kg of carbon dioxide produced by a body when it's cremated, not to mention the vaporised mercury that comes from tooth fillings"

of carbon dioxide produced by a body when it's cremated, not to mention the vaporised mercury that comes from tooth-fillings, which alone may account for 16 per cent of mercury emissions.

In the UK, natural burials, where the process of decomposition is accelerated through the use of compostable coffins that are buried nearer the surface, has become increasingly popular. To hasten things even further, some companies use coffins made of mycelium, mushroom-like fibres that contribute to the decomposition process, speeding it up three-fold. The remains can even be dug up and used as compost. Through technologies like these, which allow for greater throughflow of burial sites, it's possible that in future we might be able to unlock new parts of our landscape as places to bury our dead, including motorway embankments and cycle paths.

COMMEMORATION

For all of these possible solutions, however, one crucial factor remains: the living. Even with cremations, many people like the idea of having somewhere to visit to pay their respects, remember and mourn the dead. Even ashes are often buried or interred.

Technology can solve many parts of the space-crisis facing our graveyards and cemeteries, but our behaviours and mourning practices may also need to adjust if the human species continues to expand its populations at the current pace.

And so, the problem of space is likely to be with us for a while longer, at least until we pull upon that other human attribute, adaptability, to get us through the next stage in our evolution. All-in-all, it seems increasingly clear that the town-planners are likely to be scratching their heads for a little while longer, at least. **SF**

ALAMY ILLUSTRATIONS: MICHAEL HADDAD

WHAT ELSE CAN I DO WITH MY DEAD BODY?

Donating your body to medical science is one way to make yourself useful after death. But what if you want to do something that's not so 'run of the mill'?

CRASH CARS

Car manufacturers like to demonstrate the efficacy of their vehicles' safety features by showing you slow-motion videos of dummies getting thrown about during a collision. What they're less keen to publicise is that they've probably put dead bodies through the same tests to see how the impacts affect their internal organs.

PUT ON A SHOW

Body Worlds exhibitions feature real corpses and organs that have been preserved through plastination, a technique invented by German doctor Gunther von Hagens. If you're willing to go on display after your bodily fluids and soluble fat have been replaced by liquid plastic, you could donate your body to the Institute for Plastination.

GROW A TREE

You can still make yourself useful after you've been cremated, depending on what happens to your ashes. Scattered on soil, they'll act as a general fertiliser but if you want something more specific you can have them added to a Bios Urn, a biodegradable container that's packed with soil and used for tree seed germination.

RELEASE A RECORD

An audio recording of your voice or music that held a special meaning for you is one way that loved ones can treasure your memory. If, however, you'd like the keepsake to bear slightly more of your physical presence you can get **andvinyly.com** to press your ashes into the vinyl on which your voice and music is printed.

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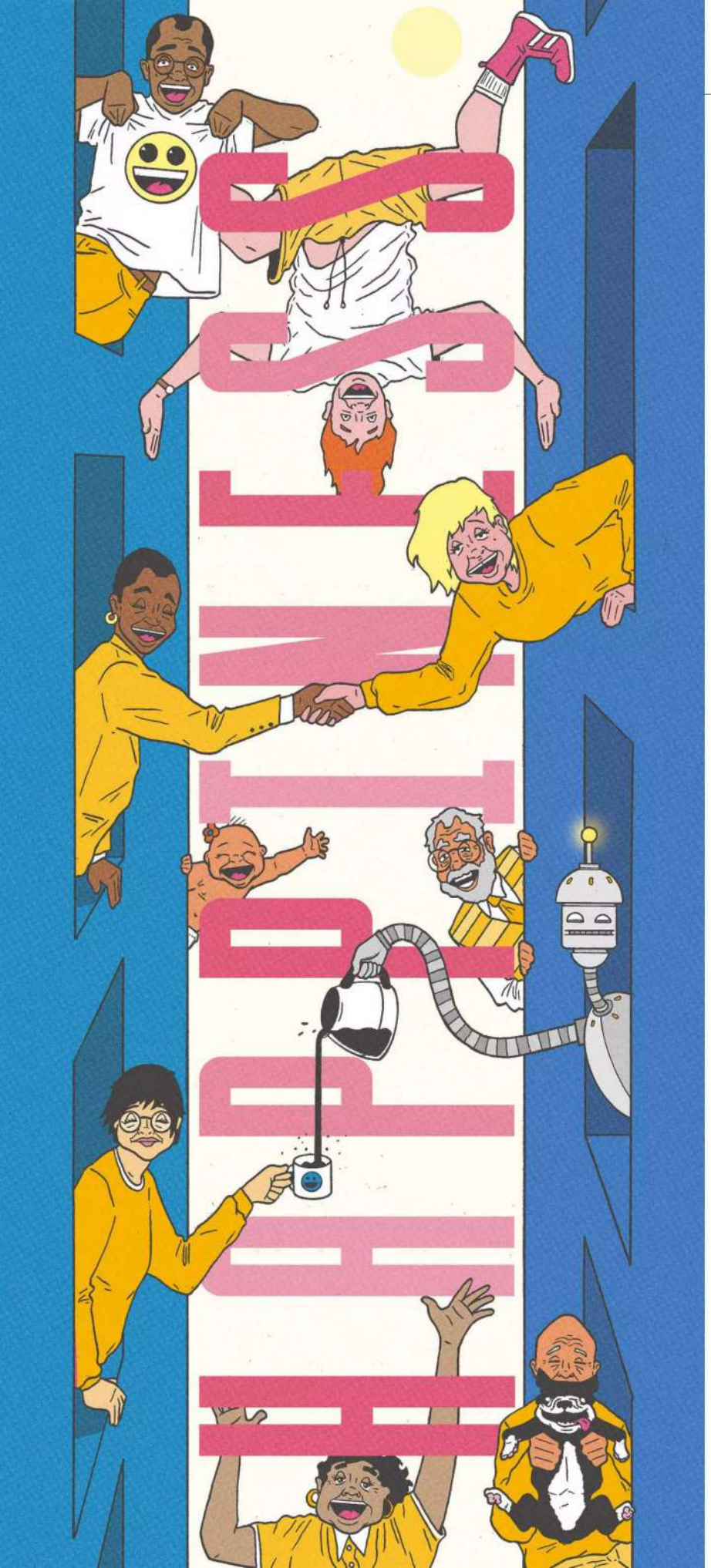

WHY DO WE FALL IN LOVE?

Is it companionship, procreation or something more? DR ANNA MACHIN **reveals what makes us so willing to become targets for Cupid's arrow**

At the most basic level, love is about survival – of the individual and the species. Humans are highly cooperative; we have to cooperate to subsist, to gain knowledge and to raise our highly dependent offspring. But cooperation isn't easy. In an ideal world we'd live in blissful solitude doing what we wanted when we wanted and not having to consider the needs of, or the threats from, others.

Group living means that we have to compete for resources, coordinate our movements, exist within a hierarchy and make sure we keep an eye out for those who might lie, cheat and steal. So, what has evolution come up with to ensure we start and then invest in these survival-critical relationships despite their costs? Love.

LOVE IS THE DRUG

Love evolved to bribe us to commence and maintain those relationships – with lovers, children, family and friends – which we require simply to stay alive and perpetuate our genes. And this biological bribery comes in the form of a set of four neurochemicals that underpin attraction and love: oxytocin, dopamine, serotonin and beta-endorphin.

Oxytocin is important during attraction as it lowers your inhibitions to starting new

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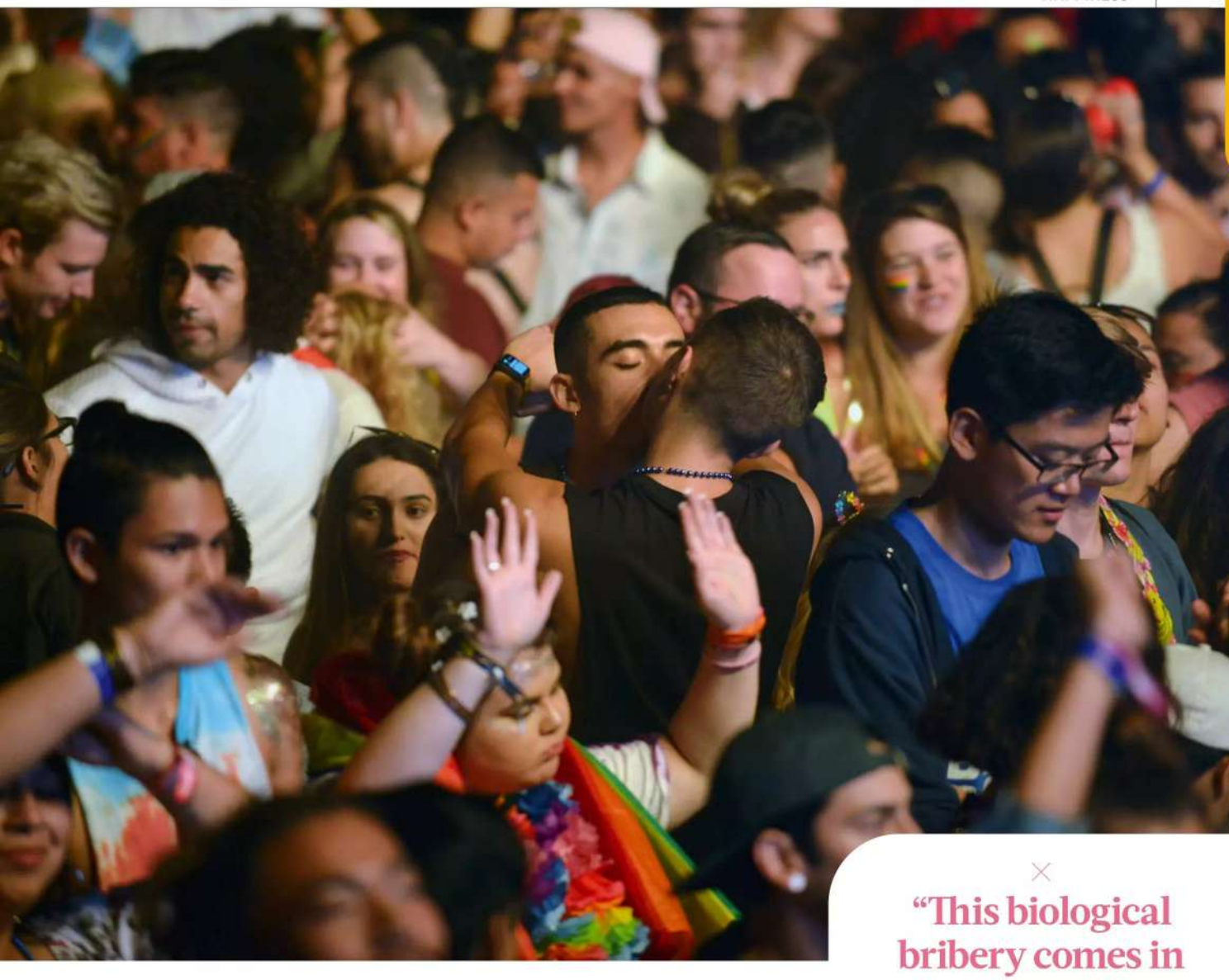

relationships by quietening the amygdala, the fear centre of your brain, meaning that you're confident when approaching a new acquaintance. Dopamine is always released at the same time as oxytocin. It's your body's reward chemical and is released whenever you do something you enjoy. In this case it rewards you for your confidence, as well as working with oxytocin to make your brain more plastic – enabling you to learn and memorise new facts about this new person – and, as the hormone of vigour, motivating you to get out of your chair and make the approach.

These chemicals act mainly in the limbic area of the brain, its unconscious core. This is because attraction, or lust, is initially a purely instinctive and unconscious sensation. Lowered serotonin unleashes the obsessive element of love. Unlike the other chemicals, serotonin drops at the start of a relationship, which is why your mind tends to be overwhelmed with thoughts about your new love.

And finally, we have beta-endorphin. This is the hormone of long-term love. Humans can be in relationships for decades and oxytocin, in particular, is not powerful enough to underpin love in the long-term. Further, oxytocin is mostly released in significant amounts only in situations related to sexual and reproductive love meaning it's not capable of underpinning friendship – a key, survival-critical human bond. But beta-endorphin can and it works because it's an opiate, like heroin or morphine. And as with heroin it's addictive. It works because we become addicted to those we love as the source of our opiate high and, when we're apart, we go cold turkey, motivating us to return to them for another euphoric hit.

"This biological bribery comes in the form of four neurochemicals that underpin attraction and love"

Because beta-endorphin underpins love, rather than lust, both the unconscious and conscious areas of our brain (respectively the limbic area and cortex) are recruited, meaning that humans can experience love as an instinctive drive or emotion involving lust, anger or delight, but also as a conscious process involving reflection, trust, empathy, attention and planning. **SF**

HOW MUCH MONEY DO YOU NEED TO BE HAPPY?

A rollover lottery win? A nice windfall that won't trouble the tax man? Or just enough for a bag of chips on the way home? HELEN RUSSELL **finds a figure that's scientifically guaranteed to put a smile on your face**

The idea that 'money can't buy you happiness' has prevailed for over a decade. Studies showed that earning above what we needed to cover our basic needs and keep us 'comfortable' was futile, and could even make us less happy. But sadly, those days are gone. Social scientists have now removed any rose-tinted spectacles to agree a new motto: the more the merrier.

In 2020, researchers analysed data from the Office for National Statistics and Happy Planet Index to find out how much money the average Briton would need to live a happy life. The answer: £33,864 or more. And it's the 'more' part that's key. A study published this year by Matthew Killingsworth of the University of Pennsylvania suggests that the more money we have, the happier we are.

This isn't purely a 'greed is good' philosophy: it has more to do with the state of the world and the 'wellness inequality' we're currently experiencing in much of it. Wealthier people tend to be in better health, and better health has an impact on happiness. Rich people who spend their money on buying more free time and investing in experiences rather than 'stuff' can also boost their happiness. Of course, happiness also comes from relationships, job satisfaction and just enjoying life. But money in the bank gives us greater options in many of these categories.

KEEPING UP WITH THE JONESES

What also impacts our happiness is how much we have compared to others. If we can maintain the same standard of living as those around us, we experience a higher level of wellbeing and so feel happier. If we can't, we don't. 'Relative deprivation', as it's known, is regardless of 'absolute poverty' – we can live in a wealthy neighbourhood or country, but if we haven't got a new car and our neighbour has, we'll be unhappy (according to the science).

The effects of relative deprivation explain why average happiness has been stagnant over time despite sharp rises in income globally. Taxes on 'status-seeking' spending as well as higher income tax may lessen the negative impact of relative deprivation on wellbeing (and explain why the high-tax Scandinavian countries often come top of the global happiness polls). But most Brits still baulk at the idea of higher taxes. So for now, having more money than our neighbours and earning at least £33k a year is the statistical sweet spot for us to be happy, but not, incidentally, our children.

A study in *Psychology Today* showed that the children of wealthy parents had a higher risk of experiencing depression, anxiety, eating disorders and substance abuse. Researchers also

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> "What also impacts our happiness is how much we have compared to others"

found that, as we get richer, we may become less ethical and less empathetic, since wealth instils a sense of freedom and the wealthier we are, the less we care about other people's problems and feelings. By contrast, psychologists at the University of California at Berkeley and San Francisco found that people on lower incomes are better readers of facial expressions and more empathetic.

So if we're not driving a fancier car than our neighbours or feeling as flush, there may be some solace in this simple fact: we're probably much nicer people. **SF**

TOP TEN
HAPPIEST CITIES

1. **Helsinki**, Finland
2. **Aarhus**, Denmark
3. **Wellington**, New Zealand
4. **Zurich**, Switzerland
5. **Copenhagen**, Denmark
6. **Bergen**, Norway
7. **Oslo**, Norway
8. **Tel Aviv**, Israel
9. **Stockholm**, Sweden
10. **Brisbane**, Australia

To compile the World Happiness Report 2020, the researchers asked citizens (aged 15 and above) to evaluate the quality of their current lives themselves using a scale from 0-10. Scandinavia dominates the top 10, although Europe and America fill most of the top 50 places (London ranked 36th). At the other end of the table are cities in places experiencing a combination of low economic development, political instability, war and catastrophic natural disasters, such as Port-au-Prince in Haiti (183rd), Gaza in Palestine (184th) and Kabal in Afghanistan (186th).

ARE WE GETTING HAPPIER?

Enjoying more good days than bad? Feel like that bounce in your step's getting bigger? HELEN RUSSELL **looks into whether we're all feeling more cheery...**

We may not feel like it, but most of us have endured our first global pandemic surprisingly well, statistically speaking. According to the latest World Happiness Report, there's been no overall change in 'positive affect' – our ability to experience positive emotions. But there has been a 10 per cent increase in the number of people who said they were worried or sad the previous day. And 22 per cent of us report that our mental health is worse than before COVID-19, with increases in depression and anxiety widespread. So while we may still be able to experience 'the good stuff', we're getting more 'sad' too.

One reason is that the physical distancing and isolation needed during the pandemic have compromised our social connections, which are vital for happiness. Many of us have felt lonelier, less connected and less supported than before – all of which makes us less happy.

Young people are falling behind most in the happiness stakes. Many have lost their jobs – according to the Office for National Statistics (ONS), the young account for nearly two-thirds of job losses since the pandemic started. Disruption to schools and higher education has been disheartening for many, too. A report by the World Health Organization found that young people in England were among the least happy in Europe prior to the pandemic, but the 2020 Good Childhood Report noted that happiness levels among 10- to 15-year-olds in the UK have fallen further still, with exam pressure and worries about friendships listed as key concerns.

Screen time isn't helping, despite the amount of time adolescents spend on social media having increased exponentially over the last decade. Time spent on digital media means less time interacting in person. Researchers in the US have found that adolescents who spend more time on electronic devices are less happy, while those who spend more time on social activities are happier. So a screen-based existence may be a double-edged sword for adolescents during a pandemic.

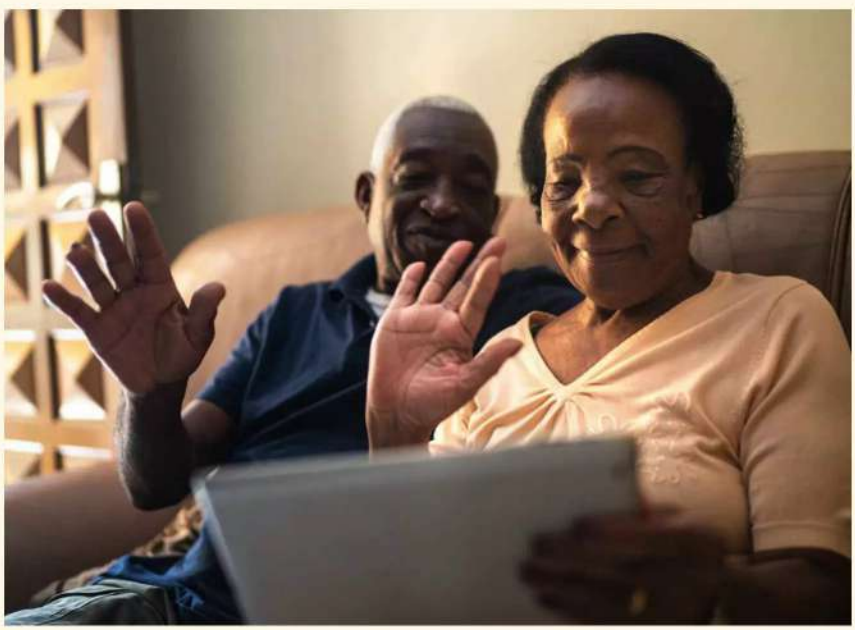
> "The physical distancing and isolation needed during the pandemic have compromised our social connections"

Women aren't having a blast, either. We're more likely to have been furloughed, figures from the ONS indicate, while research by Kantar Public suggests that when schools shut, mothers took on the bulk of home-schooling, often to the detriment of their careers. Women tend to have more friends and socialise more than men – an indicator of wellbeing in normal times that has left many feeling worse during lockdown, as the loss of connection has been felt more keenly according to research from the University of Essex.

The pandemic has also led to more job losses among women, according to the Centre for Economic Policy Research, and the World Happiness Report connects becoming

ABOVE COVID-19 has made it harder for many people to find reasons to be cheerful

RIGHT Some elderly people have reported feeling more supported and connected, despite the restrictions imposed by the pandemic



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unemployed during the pandemic with a 12 per cent drop in life satisfaction. We may be out of lockdown (for now), but the social and economic implications of the pandemic will be felt for years to come – especially by women.

THE GOLDEN YEARS

So, is anyone getting happier? Well, yes: the over 60s, according to latest World Happiness Report. They were significantly less likely to report having health problems than in previous years, despite being the age group most at risk from COVID-19. They also showed a significant increase in the perception of having someone to count on, suggesting that – for them, at least – Zoom calls scratched the social itch. The over 60s were also the first group vaccinated, so have been able to get out earlier than most.

In short, the wellbeing of the over 60s has risen significantly, especially relative to those in middle age. This shouldn't be a total surprise, since our lives typically follow a U-shaped curve, where happiness peaks at either end but troughs in our 40s. Economists David Blanchflower and Andrew Oswald started noticing patterns in life satisfaction studies in the 1990s and have now proven that contentment declines during adulthood and hits rock bottom in our 40s, before rising again.

It's often assumed that this dip is due to the burdens of middle age: job stress, money worries and caring responsibilities. But researchers have seen the same trend in chimpanzees, suggesting that the pattern is rooted in biological or evolutionary factors. One theory is that we and our chimp cousins need higher levels of wellbeing during life stages when we have fewer resources, such as youth or old age.

Another idea is that as we age and time horizons grow shorter, we invest in the things that are most important to us – such as relationships – and so derive greater pleasure from them. **SF**

QUICKFIRE

WHY DOES SCHADENFREUDE EXIST?

Pleasure at someone's misfortune is the result of your brain's constant awareness of your social status. There are many ways to improve your social status, but as it's all relative, your social status can rise if someone else's falls. So when we see someone mess up in ways that cause them to lose face, we feel a burst of satisfaction as our status is raised, at no cost to us.

DOES HAVING KIDS MAKE YOU HAPPY?

For the mother, birthing and nursing a baby causes her system to be flooded with oxytocin, the 'cuddle hormone', that amplifies emotional bonds. But this intense bonding and subsequent happiness eventually dissipates. Evidence suggests that having children can make you happier, but it can also make you feel unhappy, stressed or anxious. Overall, it seems like having children makes your emotional experiences more intense than if you don't have them.

DOES ALTRUISM REALLY MAKE YOU HAPPY?

If you want to be happier, try and make somebody else happy, according to a 2017 study. But the science is split on how long that happiness lasts. One recent study offered subjects a gift of €100 (about £85) for themselves or gift of €350 for a sick person. The group that gave the money to the sick person felt good for a short while, but those who gifted it to themselves were still happy a month later.

ARE WE GETTING LESS VIOLENT AND CAN WE ACHIEVE WORLD PEACE?

Violent conflicts and crimes remain with us, but are they still as prevalent as they once were? PROF ALEXANDER BELLAMY **examines the evidence**

In *The Better Angels Of Our Nature*, evolutionary psychologist Steven Pinker claims humans have become less violent. He thinks we've never been more peaceful and that this trend towards peace has been sustained over the long term. He finds evidence in declining rates of violent deaths per 100,000 of population, the elimination of customs such as human sacrifice, and the reduction of targeted violence such as lynching, pogroms, and spousal abuse. These changes arose from the rise of modern states, commerce, greater gender equality, cosmopolitanism and reason, despite the short-term setbacks of individual wars.

It's impossible, however, to reach back into the past and calculate the proportion of people who died violent deaths with any precision. For instance, we lack global and historical data for intimate partner violence – likely the most common type of violence. Other forms of violence, such as colonial and criminal violence, are also systematically undercounted.

A NUMBERS GAME

However one counts, the wars and genocides of the 20th Century were the deadliest in history. Using absolute rather than relative numbers, one dataset of war-related deaths since 1400 shows that violence might be cyclical rather than downwards trending. This shows that the choice of whether to use absolute or relative figures matters a great deal.

> "One dataset of war-related deaths since 1400 shows that violence might be cyclical rather than downwards trending"

During a ceasefire between Israel and Palestine in May 2021, a child in Gaza City rides past a house destroyed in the fighting

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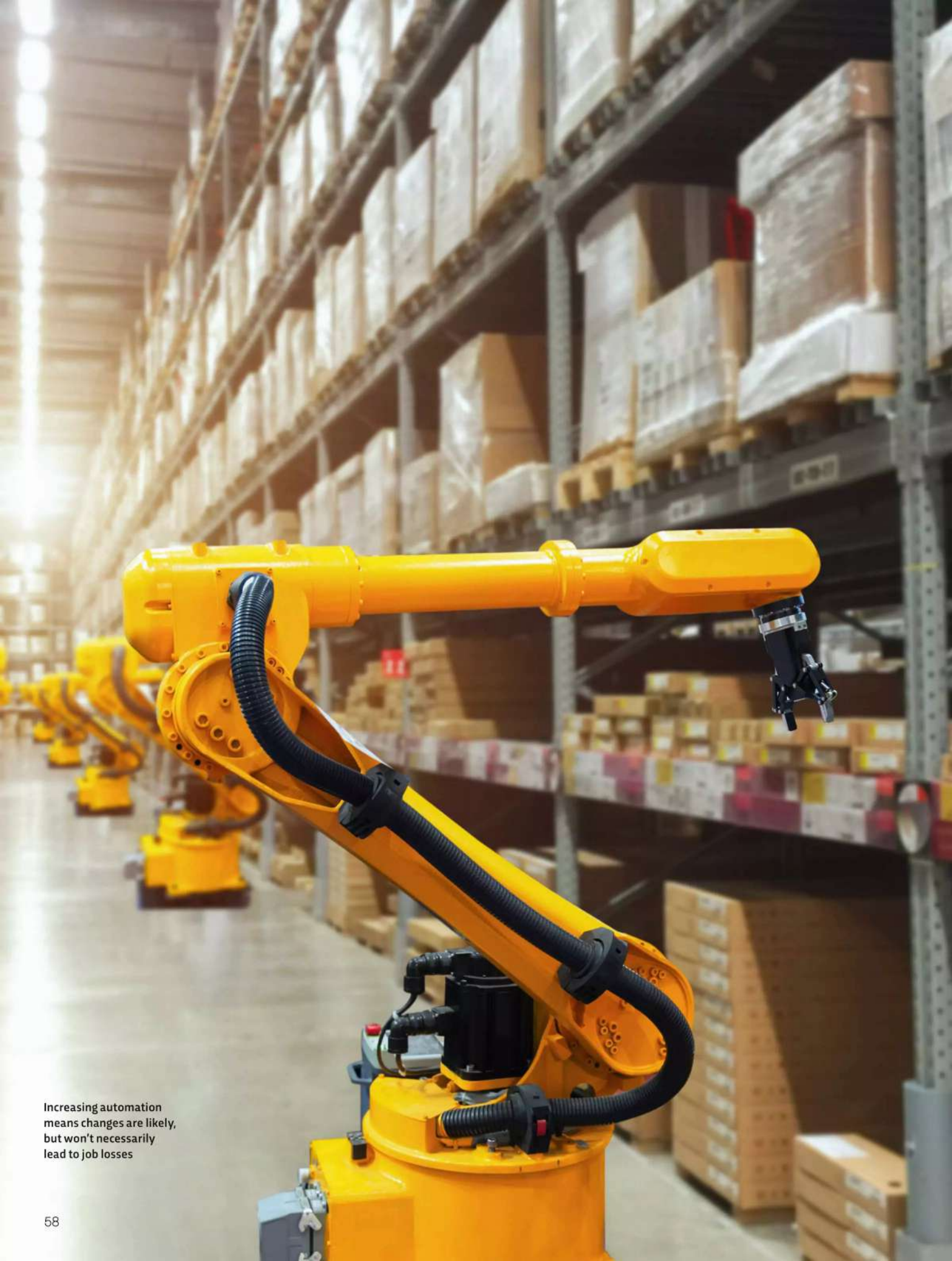
While relative estimates give us a better sense of the likelihood of dying a violent death in each period, they're skewed by overall population size. Advances in commerce and medicine mean more of us live longer, so the proportion of violent death declines even as the number in absolute terms might increase. Thus, declining relative violence may have nothing to do with our declining propensity for violence and everything to do with medicine, wealth and technology. For example, population growth, which isn't wholly related to how violent we are, means that killing more people in absolute terms can still equate to killing fewer in relative terms. If one million Brits were killed in 1600, that would be a much higher relative rate than killing five million Brits today as the population is so much larger. So if we use only relative figures we appear to be getting more peaceful when in fact we've killed four million more people.

CYCLE OF VIOLENCE

A stronger case can be made that we're getting more peaceful, just not over the long term. Data for the past two centuries is more robust, and contains evidence of declining battlefield deaths since around 1950 and declining great power war since 1600, but there are questions as to whether these are trends or merely cyclical moments. It also remains the case that the data is skewed towards international wars and that civil wars, especially before 1950, are undercounted. Better data there would likely help the peace thesis by giving us a more accurate picture of the extent of civil conflict.

Signs of greater peacefulness are clearer regionally. Western Europe has experienced unprecedented peace since 1945 and violent conflict in Southeast Asia has declined significantly since the late 1960s, as it has in South America, though violent organised crime there has increased. These regional examples show that pockets of peace can be sustained for decades. If peace can be achieved in some times and places, then why not in all times and places? **SF**



Increasing automation means changes are likely, but won't necessarily lead to job losses

WILL WE WORK IN THE FUTURE?

A job is an important part of how we find happiness in our lives (even if we don't always enjoy the work). But what if the machines start doing everything for us? HELEN RUSSELL **finds out if our working days are numbered**

Back in 1930, the economist John Maynard Keynes predicted that with technological change and improvements in productivity, we'd only be working 15 hours a week by now. But while working hours have declined by 26 per cent, most of us still average 42.5 hours a week according to Eurostat figures.

One of the things Keynes underestimated is the human desire to compete with our peers – a drive that makes most of us work more than we need to. "We don't measure productivity by how many acres we've harvested anymore, so the amount of time we spend working becomes a proxy," says Alex Soojung-Kim Pang, visiting scholar at Stanford University and author of *Rest: Why You Get More Done When You Work Less*. "Overwork as a choice, as opposed to slaving away for subsistence wages, has been part of Western society since the Industrial Revolution when some predicted that automation would create an 'excess' of leisure time. Needless to say, that didn't happen."

Thanks to computerisation and globalisation in the 1980s, managers could demand more of employees under the threat that jobs could be given to someone else. So the pressure piled on. And we took it, buckling under the strain, but shouldering the burden all the same. The psychologist Barbara Killinger writes in *Workaholics: The Respectable Addicts* about how we willingly sacrifice our own wellbeing through overwork for regular 'hits' of success.

But far from delivering productivity, value, or personal fulfilment, overwork has been proven to lead to burnout, stress, greater risk of heart disease, stroke and even shorter lifespans. Nevertheless, we persisted – until COVID-19 came along.

Those of us working from home during the pandemic put in an average of six hours of unpaid overtime a week, according to the Office of National Statistics (ONS). Those not working from home put in an average of 3.6 hours. As well as driving us to work more, COVID-19 has also accelerated the move towards automation and AI, especially for jobs with high physical proximity– from Amazon developing delivery drones to self-driving cabs. By 2050, economist Dr Carl Frey and Michael Osborne, a professor of machine learning, both at the University of Oxford, predict that at least 40 per cent of current jobs will be lost to automation, while management consultancy firm McKinsey puts the figure at 50 per cent.

JOBS FOR THE MACHINES

There are exceptions. Jobs that involve complex social interactions are beyond current robot skills: so teaching, social care, nursing and counselling are all likely to survive the AI revolution. As are jobs that rely on creativity. The same also goes for cleaning jobs, according to Frey and Osborne, due to the multitude of different objects cleaners encounter and the variety of ways those objects need to be dealt with. Interestingly, areas of the workplace traditionally dominated by women won't be so easily adopted by AI. Nor can robots pick up the 'second shift' – with women still shouldering three-quarters of all unpaid care work and doing 40 per cent more household chores according to the ONS. Robots are unlikely to assist in the 'work' of childrearing, preparing lunchboxes and doing the laundry.

> "Those of us working from home during the pandemic put in an average of six hours of unpaid overtime a week"

Those whose work falls outside the caring/cleaning/creative realms will still work in future, just differently. In about 60 per cent of occupations, according to McKinsey, it's estimated that a third of the tasks can be automated, meaning substantial changes to the way we work – and retraining. A large-scale study carried out by accountancy firm PricewaterhouseCoopers predicted that over the next 20 years, although 7 million jobs will be lost to AI, 7.2 million new ones will be created as a result. So we will work in future: we just don't know what we'll be doing yet. **SF**

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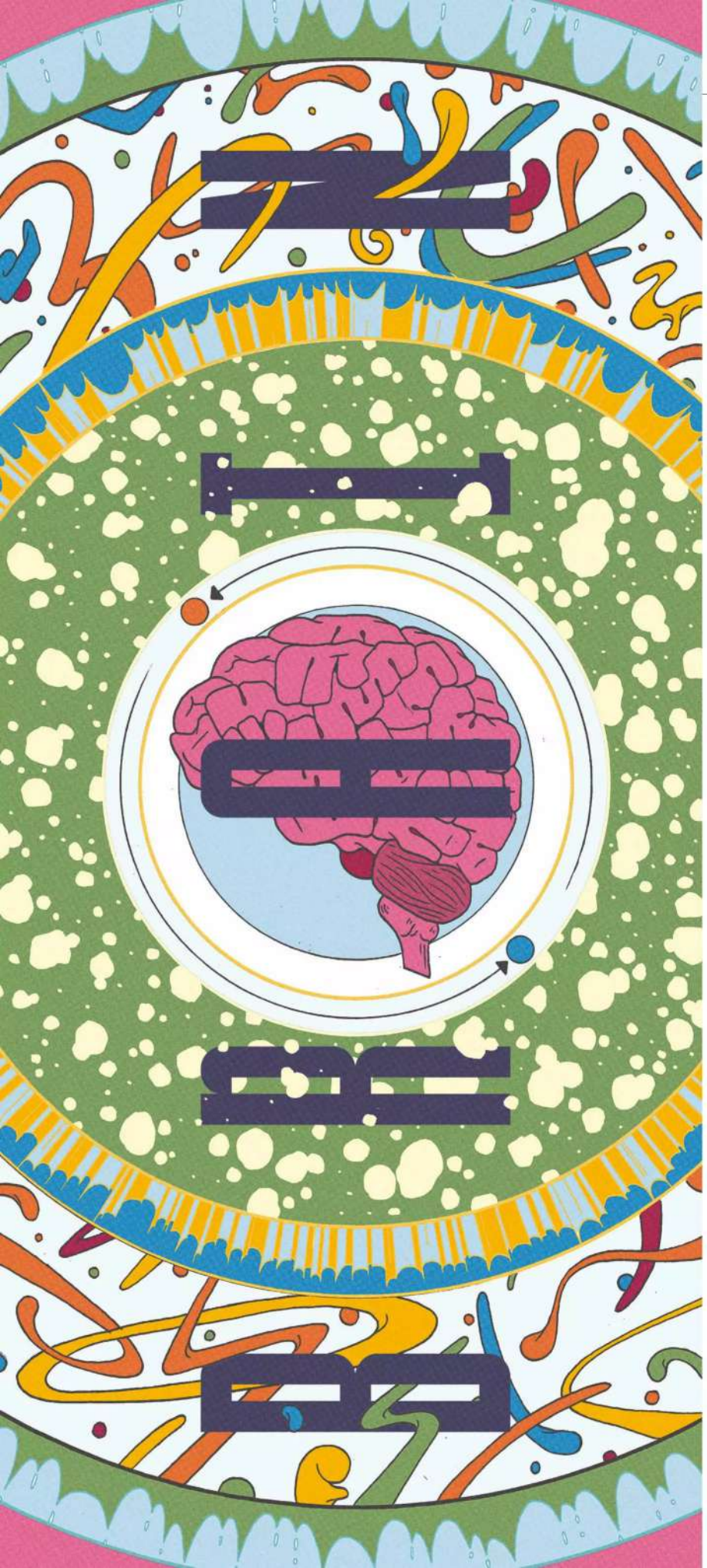


Are horror fans scared while watching a scary film, or excited?

WHAT ACTUALLY ARE EMOTIONS?

How do you feel? Are you anxious about something? Or scared? Perhaps you're happy now, but were sad before. Why do you feel this way and where do all these sensations come from? DR LISA FELDMAN BARRETT **explains...**

> "Even with this mounting evidence, the science of emotion is full of confusion"

Emotions are your brain's best guesses of what your bodily sensations mean, guided by your past experience. Your brain constructs these guesses in the blink of an eye – so rapidly, in fact, that emotions feel like uncontrollable reactions that happen *to* you, when emotions are actually made *by* you.

For a long time, scientists were sure that emotions were caused by dedicated brain circuits – a circuit for happiness, one for fear, another for anger and so on – that automatically triggered a specific pattern of facial expression, bodily state and physical action. For example, if you saw a snake, a supposed 'fear circuit' would activate, causing your eyes to widen, your heart to race and your body to prepare to flee. A given emotion was thought to be a chain reaction of coordinated events and it occurred reliably enough to indicate when a person was experiencing it.

Nevertheless, most of the scientific evidence doesn't support this view. It suggests instead that each instance of emotion is a whole-brain event. Your brain uses your past experiences to combine information from your body, such as a pounding heart, with information from the world, like the fact that you're waiting in a doctor's office for test results, to construct an emotion, such as anxiety. In a different situation, such as watching your lover walk into the room, your brain might construct an instance of excitement or lust from exactly the same pounding heart. Or if you're exercising, your brain might transform that pounding into an instance of fatigue. The meaning that your brain makes helps it plan your body's next action to keep you alive and well.

Even with this mounting evidence, the science of emotion is full of confusion. Some scientists still study brain circuits for actions, such as freezing in place, and claim that they're studying the circuits for emotion. Hundreds of studies conclude that people around the world express emotion with the same facial movements, even though most of these studies use a fragile experimental method that fails to replicate when tweaked. Companies claim to have machine learning algorithms to detect emotion from smiles and scowls, but they're detecting muscle movements, not the emotional meaning of those movements in context. Data show, for example, that people who live in large-scale, urban cultures scowl in anger less than 30 per cent of the time, so for the other 70 per cent they're doing something else with their faces in anger. And people scowl for many reasons besides anger – they might be concentrating hard or have gas. The evidence for universal expressions of emotion is even weaker in small-scale, remote societies. Therefore, scowling isn't the universal expression of anger, just one expression among many.

This muddle trickles down into the popular press, which is why you see news stories that mice have emotional facial expressions (they don't), that a brain region called the amygdala is the location of fear (it's not) and that AI systems can read your emotions (they can't). **SF**

GETTY IMAGES ILLUSTRATION: KYLE ELLINGSON

HOW MUCH OF PSYCHOLOGY CAN WE TRUST?

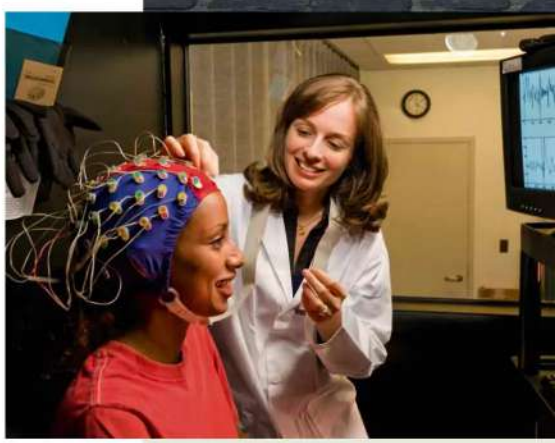
Can we still have faith in psychology in the face of the 'replication crisis'? DR LISA FELDMAN BARRETT **believes so**

The last few years have seen a lot of discussion about a 'replication crisis' or 'credibility crisis' in psychology. Various scientific findings, it seems, don't appear to be repeatable when other scientists run exactly the same experiments. Most of the focus in this crisis is on how scientists *behave*: were the original experiments biased? Was the work sloppy? Was someone gaming the system or even cheating? But perhaps a more pernicious problem is deeply rooted in how people think.

Many people who practise, use and report on the science of psychology assume that thoughts, feelings, behaviours and other psychological outcomes are the result of one or two strong factors or causes. This is called a 'mechanistic mindset'. Typical experiments attempt to isolate one or two variables, manipulate them and observe moderate to strong effects that are easy to replicate. For example, if we cause people to feel angry by showing them a film clip that violates their deeply held values, a mechanistic mindset says that they should scowl, their blood pressure should rise and they should be more likely to act aggressively.

According to a mechanistic mindset, you should be able to plop this simple experiment into any scientific lab and produce very similar results. It shouldn't matter what time of day the experiment is run, what country it's run in, what sex or gender the researchers are, what culture the participants come from, what they ate for breakfast or how much they slept, whether any of them are taking medication, and so on. Such factors are treated as noise and their influence is ignored. If the experiment doesn't produce the same observations over and over again, then the logical conclusion is that the original study was flawed and the finding is false.

A more realistic assumption, however, is that psychological outcomes do not arise from a few simple, strong factors in the first place. They emerge from an intricate web of many weak, interacting factors. This is called a complexity mindset. The brain and the body are complex, dynamic systems. Any single variable in the system will have a weak effect. More importantly, we can't manipulate one variable and assume that the others remain unaffected.



ABOVE Our brains are complex organs that can be affected by many factors. We need to account for all the factors we can if we're to understand how our brains work

EMBRACE COMPLEXITY

If we treat the brain and body like simple mechanistic systems, targeting one or two variables and leaving the rest unmeasured, then the impact of that fuller web of weak factors masquerades as a failure to replicate. The absence of replication may, in fact, be the presence of meaningful variation. The structure of that variation can be discovered and modelled only when scientists design experiments to measure and observe it. As such, psychology's most cherished experimental method – the lab experiment – may need a major overhaul in order to observe and account for complexity.

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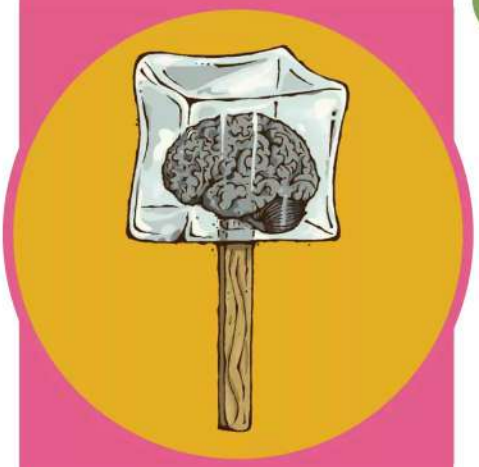
> "The absence of replication may, in fact, be the presence of meaningful variation"

Even when scientists carefully design experiments with complexity in mind, their results, when reported in the popular press, are often explained in mechanistic terms. News stories about science are simpler and more digestible when they have a pithy headline such as, "Brain circuit X causes fear" or "Gene Y causes depression".

Is there a credibility crisis in psychology? Perhaps, but not the one that tongues are wagging about. Psychological science may need to get its act together, not because its findings are unreliable, but because variation is being dismissed as noise rather than being investigated as something meaningful. Psychological phenomena arise out of complexity, not from simple, mechanistic cause-and-effect. **SF**

QUICKFIRE



WHAT CAUSES BRAIN FREEZE?

Whether you call it 'brain freeze' or an 'ice cream headache', the pain you get after taking a bite of an ice lolly hurts, albeit briefly. More studies are needed, but one theory is that the chilly substance stimulates the sphenopalatine ganglion, a cluster of nerves at the back of the palate. The other theory is that it's caused by the rapid constriction and dilation of blood vessels in the roof of the mouth.

DOES THE BRAIN EAT ITSELF?

Yes, all the time. Phagocytosis is a process whereby cells consume smaller cells or molecules, in order to remove them from the system. There are countless complex processes happening between and within our brain cells that create a lot of debris, which has to be eliminated, or else it builds up and disrupts things. But it's not just everyday housekeeping. A lot of the time, connections in the brain need to be removed or changed. And this can happen because the brain is eating itself, but in ways that make it better, not worse.

WHAT IS DÉJÀ VU?

Sorry Neo, but it looks like déjà vu – the bizarre feeling that you've experienced something that's happened before – isn't a glitch in the Matrix. It's not even a glitch in your memory. Quite the opposite: according to recent research, déjà vu is a sign of a healthy mind, occurring when the frontal regions of your brain attempt to correct an inaccurate memory.

HOW MANY SENSES DO WE HAVE?

Is there such as thing as a sense of timing? What about a sense of direction? DR LISA FELDMAN BARRETT delves into the different ways we're able to perceive the world that go beyond sight, sound, touch, taste and smell...

Assuming you equate senses with their receptors, such as the retinas in your eyes and the cochlea in your ears, then the traditional answer to this question is five – seeing, hearing, touch, smell and taste. They're called the 'exteroceptive' senses because they carry information about the external world. But your body also has receptors for events occurring inside you, such as your beating heart, expanding lungs, gurgling stomach and many other movements that you're completely unaware of. They're traditionally grouped together as another sense, called 'interoception'.

SIX, SEVEN, EIGHT...

Yet a proper answer to this question is even more complex and interesting. For one thing, your body has receptors to carry other types of information, such as temperature, that we don't usually consider to be senses. Also, some of your receptors are used for more than one sense. Your retinas, for example, are portals for the light waves you need for vision, but some retinal cells also inform your brain if it's daytime or night-time. This unnamed 'day/night sense' is the basis for circadian rhythms that affect your metabolism and your sleep/wake cycle.

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Even senses that seem most fundamental, such as vision, are intimately entwined with other senses that seem separate. For example, it turns out that what you see, and how you see it, is yoked to your brain's tracking of your heartbeat, which is part of interoception. In the moments when your heart contracts and pushes blood out to your arteries, your brain takes in less visual information from the world.

Your brain also constructs senses that you don't have receptors for. Examples are flavour, which the brain constructs from gustatory (taste) and olfactory (smell) data, and wetness, which is created from touch and temperature.

> "This unnamed 'day/night sense' is the basis for circadian rhythms that affect your sleep/wake cycle"

In fact, your brain constructs everything you see, hear, smell, taste and feel using more than just the sense data from your body's receptors. Light waves, for example, don't simply enter your eyes, travel to your brain as electrical signals, and then you see. Your brain actually predicts what you might see before you see it, based on past experience, the state of your body and your current situation. It combines its predictions with the incoming sense data from your retinas to construct your visual experience of the world around you. Similarly, when you place your fingers on your wrist to feel your pulse, you're actually feeling a construction based on your brain's predictions and the actual sense data. You don't experience sensations with your sense organs. You experience them with your brain. **SF**

WILL WE EVER RECREATE THE BRAIN ON A COMPUTER?

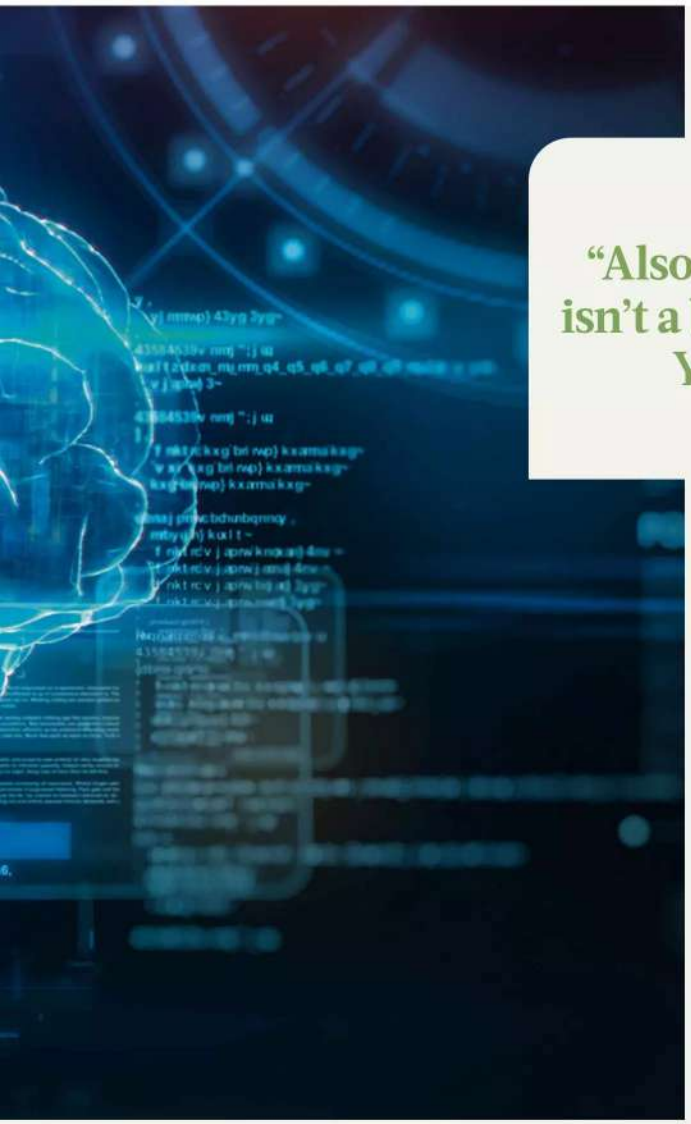
It's easy to equate brains and computers – they're both thinking machines, after all. But the comparison doesn't really stand up to closer inspection, as DR LISA FELDMAN BARRETT **reveals...**

People often describe the brain as a computer, as if neurons are like hardware and the mind is software. But this metaphor is deeply flawed. A computer is built from static parts, whereas your brain constantly rewires itself as you age and learn. A computer stores information in files that are retrieved exactly, but brains don't store information in any literal sense. Your memory is a constant construction of electrical pulses and swirling chemicals, and the same remembrance can be reassembled in different ways at different times.

Brains also do something critical that computers today can't. A computer can be trained with thousands of photographs to recognise a dandelion as a plant with green leaves and yellow petals. You, however, can

ABOVE Computer technology is advancing, but can it match the capabilities of the human brain?

RIGHT A bunch of flowers or a collection of weeds? Your brain can figure out what category these items fall into depending on the scenario



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look at a dandelion and understand that in different situations, it belongs to different categories. A dandelion in your vegetable garden is a weed, but in a bouquet from your child, it's a delightful flower. A dandelion in a salad is food, but people also consume dandelions as herbal medicine. In other words, your brain effortlessly categorises objects by their *function*, not just their physical form. Some scientists believe that this incredible ability of the brain, called ad-hoc category construction, may be fundamental to the way brains work.

Also, unlike a computer, your brain isn't a bunch of parts in an empty case. Your brain inhabits a *body*, a complex web of systems that include over 600 muscles in motion, internal organs, a heart that pumps 7,500 litres of blood per day, and dozens of hormones and other chemicals, all of which must be coordinated, continually, to digest food, excrete waste, provide energy and fight illness. Your brain's most important job is to regulate the systems of your body so you stay alive and maybe even thrive. That's probably a major reason that brains evolved in the first place. Over hundreds of millions of years, animal bodies became complicated, with dozens of systems to balance, and they needed a central controller to shuttle around blood, water, salt, oxygen and other bodily resources for survival.

"Also, unlike a computer, your brain isn't a bunch of parts in an empty case. Your brain inhabits a body"

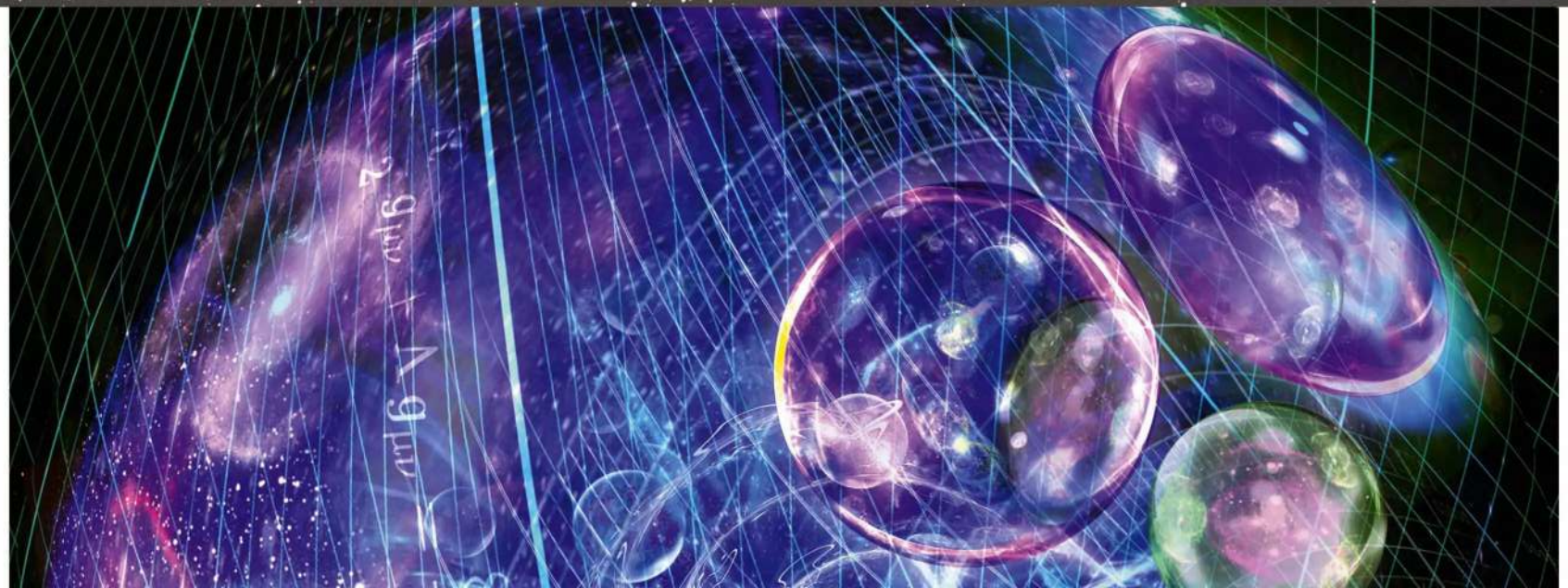
YOU CAN'T HAVE ONE WITHOUT THE OTHER

Your brain's control of your body is at the core of your mental activity. Every thought you've ever had, every concept you've ever learned, every emotion you've ever experienced and everything you've ever seen, heard, smelled, tasted or touched includes data about the state of your body. You don't experience your mental life in this way, but that's what is happening 'under the hood'.

If we want a computer that thinks, feels, sees or acts like us, it must regulate a body – or something *like* a body – with a complex collection of systems that it must keep in balance to continue operating, and with sensations to keep that regulation in check. Today's computers don't work this way, but perhaps some engineers can come up with something that's enough like a body to provide this necessary ingredient.

For now, 'brain as computer' remains just a metaphor. Metaphors can be wonderful for explaining complex topics in simple terms, but they fail when people treat the metaphor as an explanation. Metaphors provide the illusion of knowledge. **SF**

UNIVERSE



SCIENCE PHOTO LIBRARY ILLUSTRATION: KYLE ELLINGSON

DO WE NEED A THEORY OF EVERYTHING?

One theory to rule them all – is such a thing plausible? Would it unlock all the secrets of the Universe? Would we be wasting our time even searching for one? MARCUS CHOWN **reveals why finding an explanation for everything may pose more problems than it solves**

A theory of everything would do several things. Currently, we know the Universe is glued together by four fundamental forces. Thanks to Einstein, we have a theory of gravity, which views gravity as the curvature of space-time, and a 'quantum' theory of the other three fundamental forces (the electromagnetic, weak nuclear, and strong nuclear forces), which views them as arising from the exchange of force-carrying particles. Physicists believe the quantum picture is more fundamental and so the first thing they'd like for their theory of everything is a theory of quantum gravity.

But this isn't what all physicists want. Each of the three fundamental quantum forces is a consequence of a different underlying 'symmetry' and they're stitched together into the patchwork theory of the 'Standard Model'. Physicists would like to show that all the forces, including gravity, are the consequences of a single symmetry principle. But this prejudice to have a 'beautiful' theory is a human desire and may not necessarily be respected by nature. A theory of everything may exist, but it might be an ugly patchwork.

Even if such a theory does exist – a neat set of equations that can be fitted on a stamp – it'll be highly compact and abstract. And it may not tell us much that's useful. It won't be obvious, for instance, that the theory unlocks the mystery of consciousness. Einstein's theory of gravity is an elegant theory, but its consequences are hard to deduce. Similarly, it's likely that the consequences of a theory of everything will be hard to deduce as well and take generations of effort by physicists.

Even if physicists find a theory of everything, they'll be left with the question of why this set of mathematical equations rather than another? The physicist Stephen Wolfram, who thinks the Universe is computer-generated, believes he has sidestepped this problem by claiming the Universe isn't being created by a single computer program, but by *all possible computer programs*.

> **"This prejudice to have a 'beautiful' theory is a human desire and may not necessarily be respected by nature"**

All of this is reminiscent of Gödel's incompleteness theorem in mathematics. Back in 1930, the Austrian mathematician Kurt Gödel examined the claim that all the 'theorems' of mathematics could be deduced from a few assumptions, or 'axioms'. Think of the theorems as balloons floating above the ground of axioms, but tethered by logic. Gödel found that there would always be theorems that were true, but that couldn't be deduced from the axioms – free-floating balloons – and therefore mathematics is incomplete. Given that mathematics is the language of physics, it's conceivable that physics is incomplete too and a theory of everything will turn out to be nothing more than a mirage. **SF**

KAMIOKA OBSERVATORY, ICRR (INSTITUTE FOR COSMIC RAY RESEARCH), THE UNIVERSITY OF TOKYO, SCIENCE PHOTO LIBRARY

Photomultiplier tubes in Japan's Super-Kamiokande detector facility, buried 1km underground, stand ready to pick up neutrinos generated 295km away in Tokai

WHERE DID ALL THE ANTIMATTER GO?

Some of our antimatter must be missing, given the amount of matter leftover in the Universe. MARCUS CHOWN **investigates...**

Particles and antiparticles have opposite properties, such as electric charge. For instance, the antiparticle of the negative electron is the positive positron. Every physics process we know of creates equal amounts of matter and antimatter. When a particle meets its antiparticle however, it 'annihilates', ultimately into high-energy photons. As such, the Universe should contain no matter or antimatter, and just be a sea of photons. Instead, it contains enough matter to make about two trillion galaxies and, as far as we can tell, no antimatter.

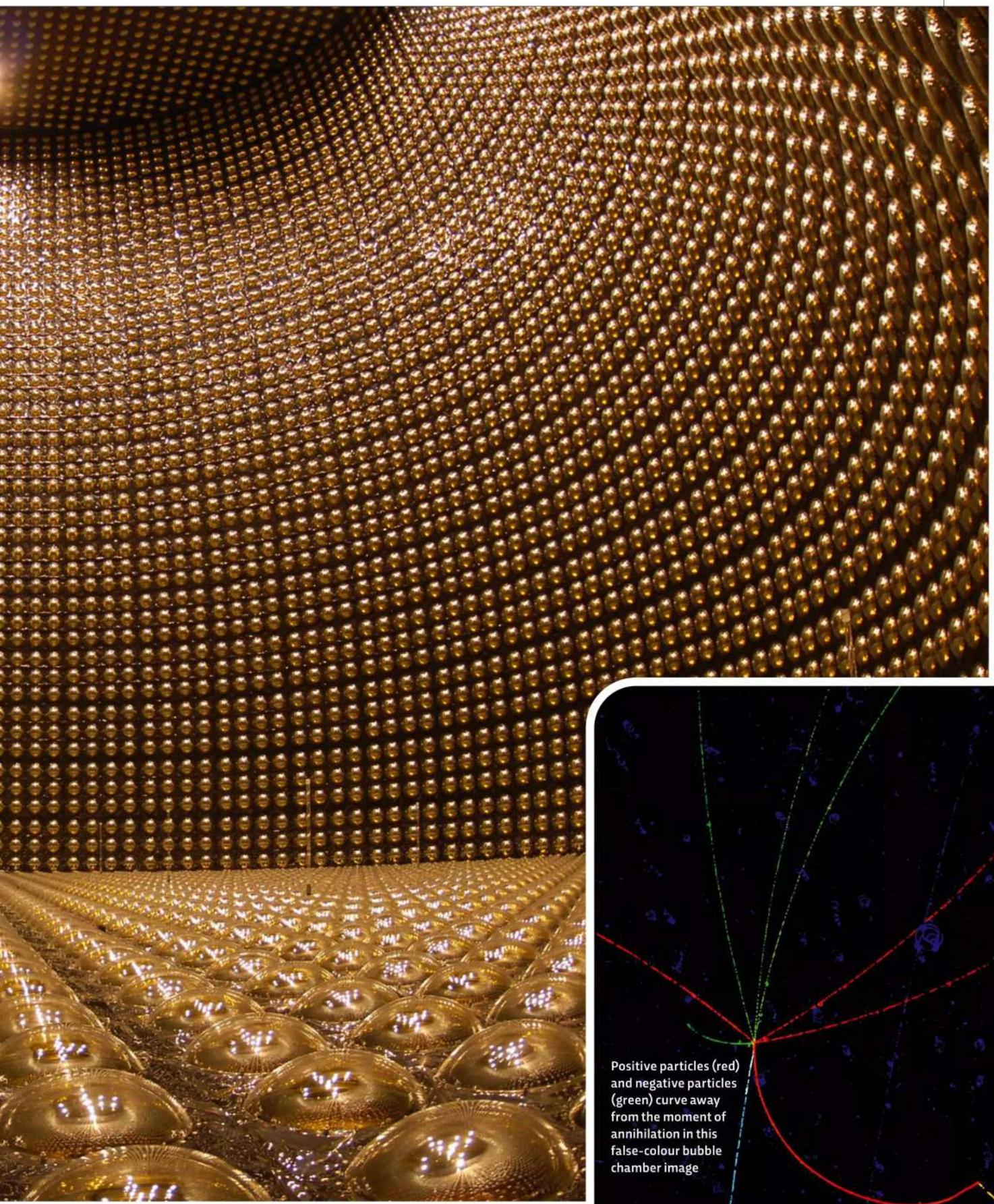
A clue to what happened to all the antimatter comes from the fact that the 'afterglow' of the Big Bang (the cosmic background radiation) contains about 10 billion photons for every particle of matter in today's Universe. This tells us that, in the Big Bang, there were 10 billion and one particles of matter for every 10 billion of antimatter, and after an orgy of annihilation there were 10 billion photons for every particle of matter.

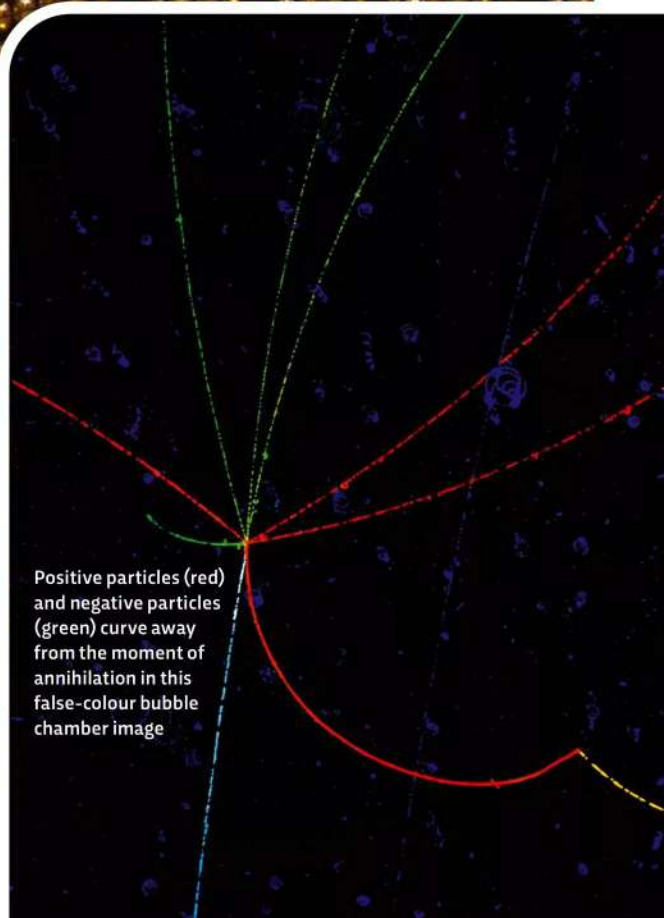
Physicists have long been looking for a subtle asymmetry in the laws of physics that explains this excess of matter over antimatter in the Big Bang. And they think they may have found it in the behaviour of neutrinos. Neutrinos are ghostly subatomic particles that rarely interact with matter. (Hold up your thumb; about 100 billion neutrinos, generated by nuclear reactions in the Sun, pass through your thumbnail every second.) Neutrinos come in three types and each neutrino continually changes from an electron-neutrino to a muon-neutrino to a tau-neutrino and back again.

NEUTRINO BEHAVIOUR

Since 2016, physicists at the T2K experiment in Japan have been trying to show that neutrinos behave differently to antineutrinos. To do this, they generate beams of muon-neutrinos and muon-antineutrinos at a facility in Tokai and send them to the giant underground Super-Kamiokande detector, 295km away. So far, they've detected more electron-neutrinos and fewer electron-antineutrinos than expected, suggesting neutrinos do behave differently to antineutrinos. It's a small effect that needs to be confirmed, but it could provide the mechanism for creating a matter-dominated Universe.

Neutrinos have too little mass to have made much difference to the Universe. Crucially, however, they only spin clockwise around their direction of flight, and physicists wonder whether neutrinos and antineutrinos had super-heavy partners with opposite spin in the Big Bang. These ultra-heavy particles would have been able to form only in the high-energy conditions of the Big Bang and would have quickly decayed into the particles we see today. In doing so, they could have imprinted their asymmetry on the cosmos, producing the 10 billion and one particles of matter for every 10 billion of antimatter needed to explain why we live in a Universe exclusively of matter. **SF**





Positive particles (red) and negative particles (green) curve away from the moment of annihilation in this false-colour bubble chamber image

QUICKFIRE

WITHOUT ALL THE EMPTY SPACE, HOW BIG WOULD THE UNIVERSE BE?

It's said atoms are largely empty space – protons and neutrons one million-billionth of a metre across with electrons circling in orbits over 100,000 times larger. Quantum theory shows this model is misleading, but ignoring this, astronomers estimate there are roughly 10^{80} atoms in the visible Universe. Crammed together, they'd make a ball that would fit inside the Solar System.

HOW MANY PIECES OF SPACE JUNK ARE ORBITING EARTH?

There are currently 28,600 catalogued pieces being tracked, according to the European Space Agency. But that's only the bits that are large enough (upwards of 5cm) and near enough to register on radar. Statistical models estimate there could be as many as 900,000 pieces between 1cm and 10cm, and up to 128 million pieces sized 1mm to 1cm.

HOW DO WE KNOW HOW OLD THE UNIVERSE IS?

We deduce the age of the Universe (13.82 billion years old) from observations, coupled with an assumption that the fundamental physical laws of today also operated in the past. We know that the galaxies we observe are receding, so the Universe is expanding. If the rate of expansion were constant, that would give us a point in time when it was zero size, which we could label the beginning: the Big Bang. But the rate of expansion seems to be increasing. This expansion tells us the Universe as we know it hasn't been here forever.

ALAMY X2

COULD WE BUILD AN ELEVATOR TO THE MOON?

Blasting off in a rocket is an expensive, difficult and dangerous way to get to the Moon. COLIN STUART **looks into another way we could travel there and back**

What do you see when you look at the Moon? Beauty? Craters? Some people see dollar signs. You'll occasionally see our only natural satellite billed as 'Earth's eighth continent' because it's full of resources that are hard to ignore. A rare form of helium, helium-3, could be used in fusion power stations here on Earth. Rare elements, such as neodymium, could be extracted and returned home for use in smartphones and other electronics.

But how do we get them here without blowing all the profits on rockets? According to a study published in 2019, a lunar elevator could be the answer. A cable anchored to the lunar surface would stretch most of the 400,000km (250,000 miles) home. It couldn't be directly attached to the Earth, due to the relative motions of the two objects, but it could terminate high in Earth orbit. That would have the added benefit of placing it above the bulk of our space junk, a growing problem as we launch ever more satellites. Solar-powered robotic shuttles could move up and down the cable, acting as a conveyor belt to ferry precious resources our way.

GOING UP?

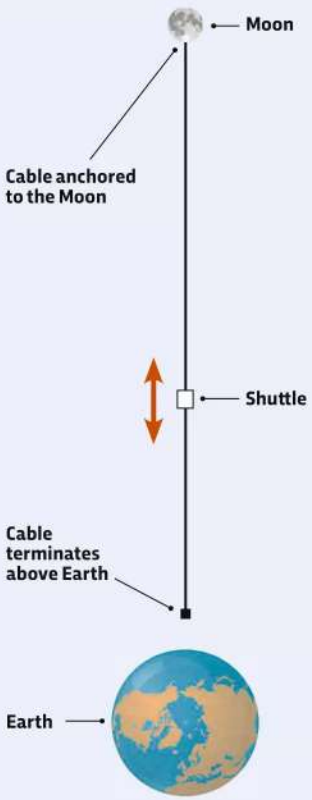
It may sound like an outlandish prospect, but Zephyr Penoyre and Emily Sandford – the two University of Columbia astronomy PhD candidates behind the study – believe we could pull it off for a few billion US dollars. To put that into context, Jeff Bezos liquidates $1bn (over £700m) of his Amazon stock every year to fund his Blue Origin space tourism company. NASA's Artemis programme, which is sending the first female astronaut and first astronaut of colour to the Moon later this decade, is costing $86bn (£60bn). Such is the value of the Moon's resources, a separate study estimated that a lunar elevator would pay for itself within just 53 trips.

The cable, which would be no thicker than a pencil, would weigh 40 tonnes – well within the remit of modern rockets,

It's not as dramatic as a rocket launch, but catching a lift would be a more economical method of getting into space in the long term

HOW COULD IT WORK?

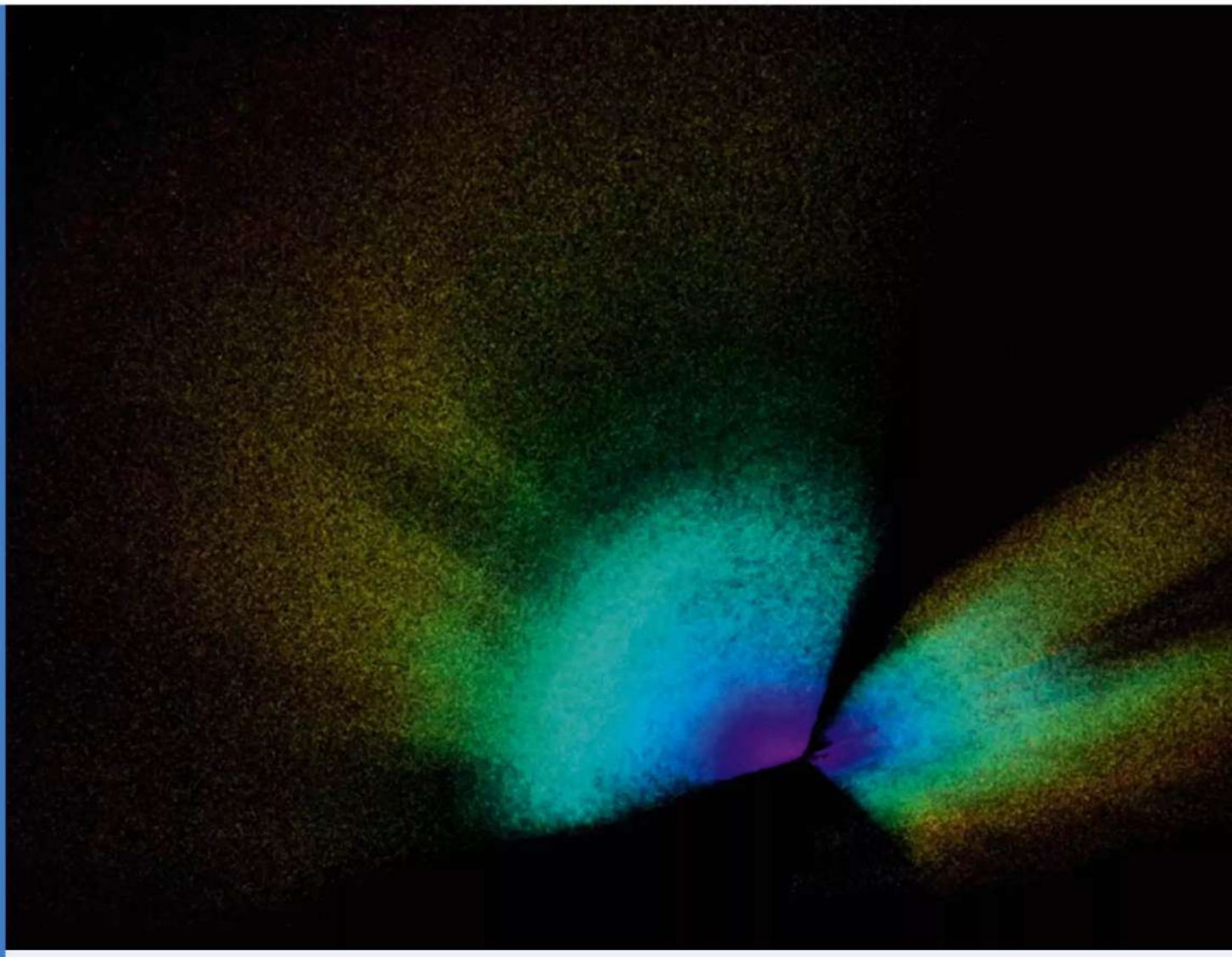
According to the University of Columbia study, a cable could be attached to the lunar surface, terminating above Earth. Solar-powered shuttles travelling up and down the cable would ferry goods from the Moon.



such as SpaceX's Starship. Unlike a space elevator that would travel from Earth's surface into space, a lunar elevator stopping slightly shy of our planet wouldn't have to contend with huge gravitational forces. The Moon has no atmosphere either, which simplifies matters. That means the cable could be made from existing materials, such as Kevlar, instead of the yet-to-be-invented super-strong materials needed for an Earth-to-space elevator.

We could also combine the two. In April 2021, Chinese state-run media presented the country's idea for a 'Sky Ladder'. This would see a spacecraft winched up an elevator from Earth's surface to a waiting space station, before being flung towards the Moon where it would meet another elevator that would lower it down to the lunar surface.

The idea of space elevators has been around for over a century without much progress. But if enough people – or, more likely, corporations – become enamoured with the chance of making big bucks, we could see the lunar equivalent of a gold rush in the decades ahead. Elevators could well turn out to be a way to keep costs down and profits literally sky-high. **SF**



DOES THE UNIVERSE HAVE AN EDGE?

It's all very well saying the Universe encompasses everything, but everything has to end somewhere, right? Well, not exactly, as MARCUS CHOWN **explains...**

If by 'Universe' we mean 'everything there is', then the Universe clearly does not have an edge. If we thought it did, we would be guilty of not including everything! But people often ask the question in a slightly different way, which assumes there is an edge: "If the Universe is expanding," they say, "what is it expanding into?" This, though, misunderstands what is meant by 'expanding Universe'.

In Berlin in 1915, at the height of WWI, Albert Einstein came up with a revolutionary theory of gravity, which supplanted Newton's and, in 1916, he applied it to be the biggest source of gravitating mass he knew of: the Universe. What Einstein's theory showed (it was others who spotted this, not Einstein) was that the Universe

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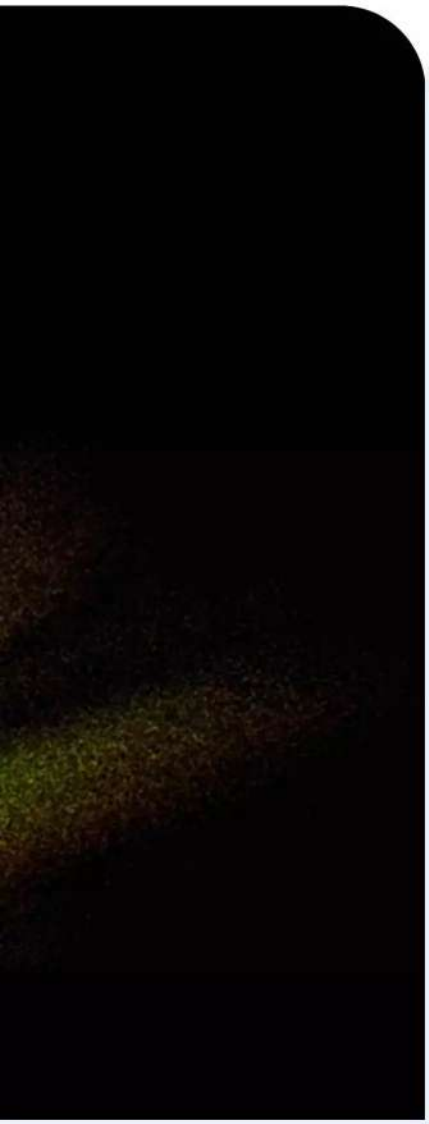
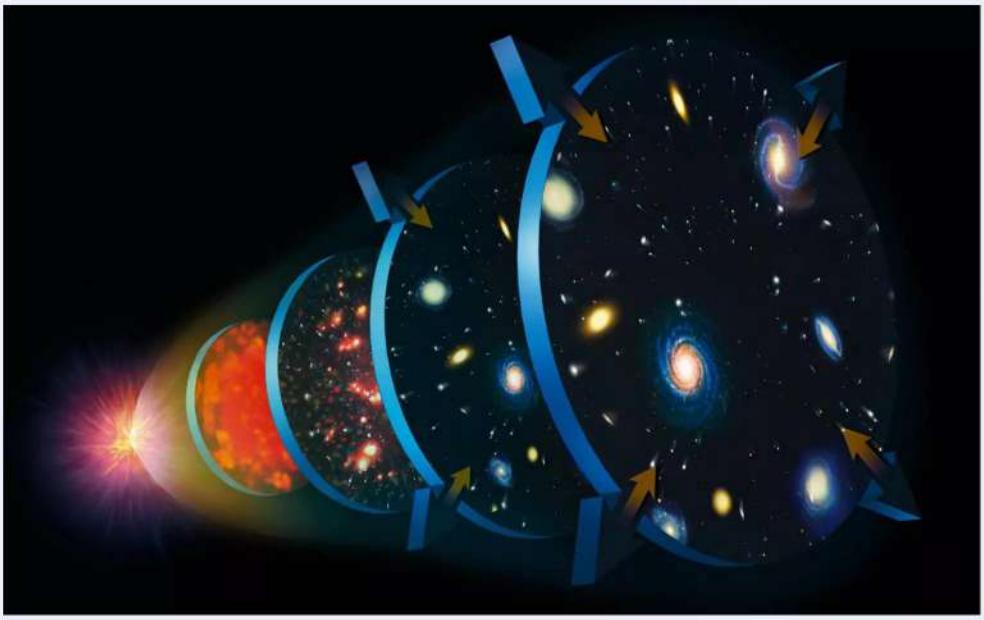


"The American astronomer Edwin Hubble discovered that galaxies are flying away from each other like pieces of cosmic shrapnel in the aftermath of a titanic explosion – the Big Bang"



ABOVE A map showing 11 billion years of the Universe's history, with galaxies closest to Earth in purple and blue, and those furthest away in yellow and red

ABOVE RIGHT The expansion of the Universe began 13.82 billion years ago with the Big Bang (left) and continues to accelerate today due to dark energy (black arrows), despite gravity attempting to slow it (orange arrows)

could not be still but had to be in motion: either expanding or contracting. In fact, in 1929, the American astronomer Edwin Hubble discovered that galaxies are flying away from each other like pieces of cosmic shrapnel in the aftermath of a titanic explosion – the Big Bang.

This, in essence, is what we mean by the expansion of the Universe: that the distance between galaxies is growing. Einstein's theory could easily describe a Universe that goes on forever and therefore has no edge, or one that curves back on itself like a higher-dimensional version of the surface of a ball, and so also has no edge. In the latter case, confirmation would be to observe the same galaxies on opposite sides of the Universe when we look far enough away with our telescopes.

Of course, others will say the Universe does have an effective edge, because it was born 13.82 billion years ago in the Big Bang. We can therefore see only those galaxies whose light has taken less than 13.82 billion years to reach us (about two trillion). Those galaxies exist in a sphere of space centred on the Earth that we call the 'observable Universe'. It's actually about 92 billion light-years across as the Universe 'inflated' far faster than the speed of light in its first split-second of existence.

The observable Universe is bounded by a 'cosmic horizon', much like the horizon at sea. Just as we know there's more ocean over the horizon, we know there are more galaxies (possibly an infinite number) beyond the cosmic horizon. Their light simply hasn't had time to reach us yet. **SF**

Superstring theory (depicted by this conceptual illustration) seeks to unify gravitational force with all the other fundamental forces

WHAT'S INSIDE THE FIFTH DIMENSION?

What else could there be beyond the three dimensions of space and one of time? And how can we begin to conceive of it? MARCUS CHOWN **delves into the mind-warping possibilities...**

In 1905, Albert Einstein showed in his Special Theory of Relativity that space is intimately connected to time via the cosmic speed limit of light and so, strictly speaking, we live in a Universe with four dimensions of space-time. For everyday purposes however, we think of the Universe in three dimensions of space (north-south, east-west, up-down) and one dimension of time (past-future). In that case, a fifth dimension would be an extra dimension of space.

Such a dimension was proposed independently by physicists Oskar Klein and Theodor Kaluza in the 1920s. They were inspired by Einstein's theory of gravity, which showed that energy, most commonly mass-energy, warped four-dimensional space-time. Since we're unable to perceive these four dimensions, we attribute motion in the presence of a massive body, such as a planet, not to this curvature but to a 'force' of gravity. Could the other force known at the time (the electromagnetic force) be explained by the curvature of an extra dimension of space? Kaluza and Klein found it could. But since the electromagnetic force was 1,040 times stronger than gravity, the curvature of the extra dimension had to be so great that it was rolled up much smaller than an atom and would be impossible to notice. When a particle, such as an electron, travelled through space, invisible to us it would be going round and round the fifth dimension, like a hamster in a wheel.

Kaluza and Klein's five-dimensional theory was dealt a serious blow by the discovery of two more fundamental forces that operated in the realm of the atomic nucleus: the weak and strong nuclear forces. But the idea that extra dimensions explain forces was revived half a century later by proponents of 'string theory' in which the fundamental building blocks of the Universe are viewed not as particles, but tiny 'strings' of mass-energy. To mimic all four forces, the strings vibrate in 10-dimensional space-time, with six space dimensions rolled up far smaller than an atom.

STRINGS, ISLANDS AND MATTER FROM THE FUTURE

String theory gave rise to the idea that our Universe might be a three-dimensional island, or 'brane', floating in 10-dimensional space-time. This raised the intriguing possibility of explaining why gravity is so extraordinarily weak compared with the other three fundamental forces. While they're pinned to the brane, goes the idea, gravity leaks out into the six extra space dimensions, enormously diluting its strength on the brane.

There is a way to have a bigger fifth dimension, which is curved in such a way that we don't see it, and this was suggested by the physicists Lisa Randall and Raman Sundrum in 1999. An extra space dimension might even explain one of the great cosmic mysteries: the identity of 'dark matter', the invisible stuff that appears to outweigh the visible stars and galaxies by a factor of six. This year, a group of physicists from Johannes Gutenberg University in Mainz, Germany, proposed that the gravity of hitherto unknown particles propagating in a hidden fifth dimension could manifest itself in our four-dimensional Universe as the extra gravity we currently attribute to dark matter. Though an exciting possibility, it's worth pointing out that there's no shortage of possible candidates for dark matter, including subatomic particles known as axions, black holes and reverse-time matter from the future! **SF**

> **"An extra space dimension might even explain one of the great cosmic mysteries: the identity of 'dark matter'"**

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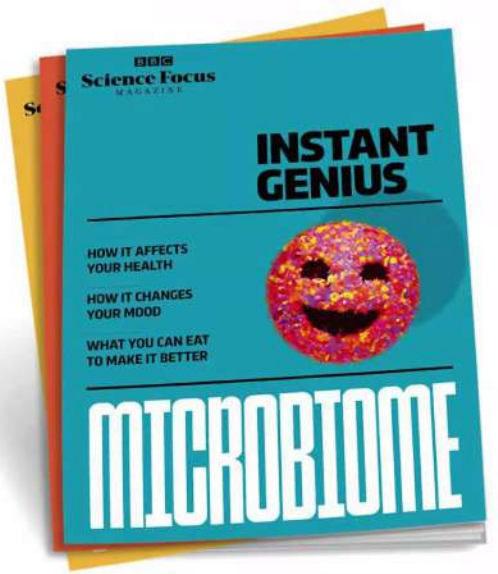

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Q&A

OLYMPICS SPECIAL

YOUR QUESTIONS ANSWERED

... WHY DOESN'T SAND STICK TO BEACH VOLLEYBALL PLAYERS?
... WILL WE REACH A POINT WHERE SPORTS RECORDS CAN NO LONGER BE BROKEN?
... WHY DO OLYMPIANS BITE INTO GOLD MEDALS?
... WILL AI REPLACE MUSICIANS?
... WHAT IS THE DEADLIEST OLYMPIC SPORT?
... WHY DO ELITE DIVERS HAVE TINY TOWELS?
... DO WOMEN MAKE FOR BETTER ENDURANCE ATHLETES THAN MEN?
... COULD ANYONE BECOME AN OLYMPIAN WITH ENOUGH PRACTICE?
... WHY DOES FINISHING SECOND FEEL SO MUCH WORSE THAN THIRD?
... HOW DOES THE FOSBURY FLOP WORK?

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DR CHRISTIAN JARRETT Neuroscience expert

DR NISH MANEK Medical expert and GP trainee

DR HELEN PILCHER Biologist and science writer

LUIS VILLAZON Science and technology writer

ILLUSTRATION: DANIEL BRIGHT

HOW DO HORSES GET TO THE OLYMPICS?

While the coronavirus pandemic has made things increasingly difficult for world-class athletes to travel, spare a thought for all the horses that cross continents for the Olympic and Paralympic equestrian events.

Just like in previous years, all horses competing in this year's tournament are expected to complete seven days of pre-export quarantine. During this time, they're tested (through a swab and blood sample) for certain diseases, including equine influenza. Although there's no evidence that horses can carry and transmit COVID-19, the animals can spread equine coronavirus (known as ECoV), a highly contagious horse-to-horse virus first identified in the early 2000s.

But how are horses actually transported? By plane. Don't worry, you won't have to squeeze past one slumped in the aisle seat as you jet off on your holiday. The British Equestrian Society (the body responsible for Team GB's equine athletes) fly the animals on specially chartered flights in their very own business class with wide stalls for maximum comfort.

While not typically sedated unless they have a bad reaction to flying, horses often appear to enjoy their time aboard planes, surrounded by food (a type of hay with high moisture content) and a team of staffers and vets to look after them throughout the journey.

After landing, the horses are kept in isolation at Tokyo's Olympic Village for the duration of the Olympics and are cared for by professionals throughout their two-month stay. Of course, during this time the horses get the chance to win bronze, silver or gold medals for their riders – but not themselves. Although the animals aren't handed a chunk of precious metal, they do earn a ribbon for any victory. That beats a lump of sugar, right? ***KB***

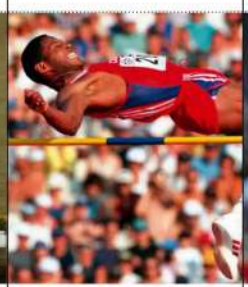
WHY DOESN'T SAND STICK TO BEACH VOLLEYBALL PLAYERS?

Sand grains tend to stick to each other and to our skin when water is present, via tiny liquid bridges held together by surface tension. However, official volleyball sand is designed to have excellent drainage, which minimises the water content. The International Volleyball Federation (FIVB) has strict specifications for sand, which must be sieved so that it's neither "too coarse" nor "too fine to cause dust and stick to the skin". The grains also have to be naturally weathered to give rounded edges that aid flow and drainage. ***ED***

TOP TEN

Animal athletes

As Tokyo welcomes the world's best athletes to the 32nd Olympic Games, let us also celebrate the athletic abilities of the wider animal kingdom. From fencing flatworms, to the big cat that could beat Usain Bolt, please be upstanding for the world's greatest animal Olympians.

	1 LONGEST JUMPER	2 HIGHEST JUMP	3 FASTEST SPRINTER	4 FASTEST SWIMMER
HUMAN				
	Mike Powell (USA) **8.95m**	Javier Sotomayor (Cuba) **2.45m**	Usain Bolt (USA) **44.72km/h**	Michael Phelps (USA) **7.08km/h**
ANIMAL				
	Snow leopard **15m**	White-tailed jackrabbits **5.7m**	Cheetah **114.5km/h**	Sailfish **40km/h**

WILL WE REACH A POINT WHERE SPORTS RECORDS CAN NO LONGER BE BROKEN?

In 1908, the record for a marathon was 2:55:18. Over the next 50 years, the record was beaten 22 times, knocking more than 40 minutes off the time. But in the 50 years after that, the time dropped by only another 10 minutes and since 2002 the record has improved by less than four minutes. This broad pattern has been repeated across nearly all sports; there are occasionally jumps due to changes in regulations or the introduction of new techniques and equipment, but the improvement due to raw muscular performance has got smaller.

Various studies have attempted to extrapolate this trend to find the limits of the human body. For instance, research at the University of Wyoming concluded that 100m sprint times aren't limited by how much force a runner can apply to the ground, but by how quickly they can swing their legs forward again after each stride. Other studies suggest a fastest possible 100m sprint time of around 9.44s – just 0.14s faster than Usain Bolt's current world record, set in 2009.

Despite these biological limits, there will never be a time when Olympic records are no longer broken, for one simple reason: the spectacle. Each event must adapt to give us the thrilling prospect of new records, or it'll be replaced by other events that do. This may be by adding handicaps or banning certain equipment, or it could be by using ever more accurate timing. Perhaps one day we'll cheer on sprinters running in a wind tunnel against a 30km/h headwind, chasing records timed to microsecond precision. ***LV***

5	6	7	8	9	10
DEEPEST DIVER	**FASTEST SKYDIVER**	**WEIGHTLIFTING**	**MARATHON RUNNING**	**FASTEST PUNCH**	**FENCING**
Ahmed Gabr (Egypt) **332m**	Alan Eustace (USA) **1,323km/h**	Lasha Talakhadze (Georgia) **485kg**	Eliud Kipchoge (Kenya) **2:01:39 hours**	Keith Liddell (USA) **20m/s**	Daniele Garozzo (Italy) **2016 Olympic gold medallist**
Cuvier's beaked whale **2,992m**	Peregrine falcon **320km/h**	African elephant **1,000kg**	Ostrich **45 minutes**	Mantis shrimp **23m/s**	Flatworm **Fence with their penises as part of courtship**

GETTY X11, SHUTTERSTOCK X4, ALAMY X4

WHY DO OLYMPIANS BITE INTO GOLD MEDALS?

Biting medals is a press-pleasing tradition. It is thought to be inspired by the US Gold Rush when miners needed to check nuggets for soft gold as opposed to fool's gold.

Weighing between 500g and 800g, gold medals are actually made from silver coated with at least 6g of pure gold. A 'gold' medal's value depends on global markets, but those issued in Rio in 2016 were estimated to be worth over £360 each. Medals for the delayed 2020 Tokyo Olympics are made from recycled metals.

The host country's mint is responsible for making medals, following International Olympic Committee specifications. Solid gold medals haven't been handed out since 1912. ***ED***

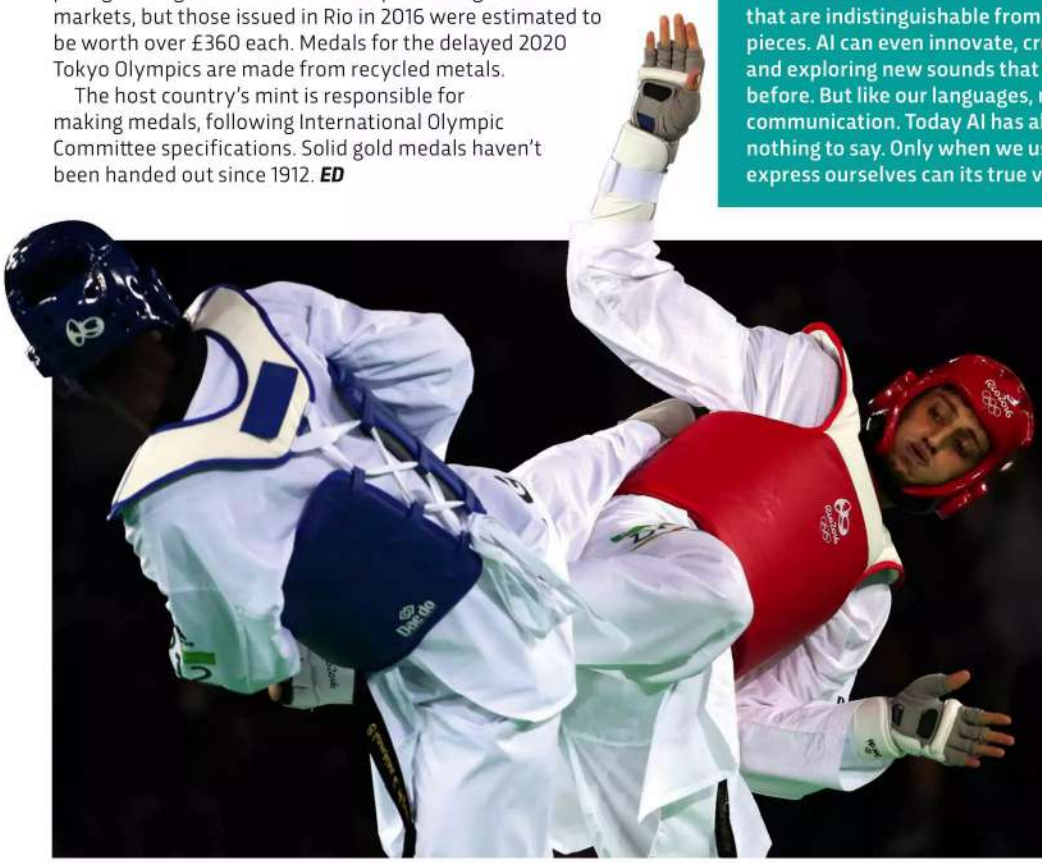
WILL AI REPLACE MUSICIANS?

Artificial intelligence (AI) is now giving us the next generation of electronic music, this time by using machine learning to understand sounds, patterns and styles of music and lyrics, and then generating new versions. This was the approach used to create 'The official Tokyo 2020 beat', which saw an Intel AI use thousands of pieces of music reflecting themes of sports, Japanese culture, daily life and nature, to compose hundreds of options, before the final version was chosen by the Japanese public.

AI music is becoming a new industry, with start-ups inventing faster and easier music composition software, such as JukeDeck, a UK-based AI music start-up recently acquired by TikTok, which automatically interprets video and sets music to it.

Many recording artists are experimenting with AI for lyric generation, following the example David Bowie set in the 1990s with the song *Hallo Spaceboy*. Others are using AI to make new neural synthesiser sounds, such as Grimes on the track *So Heavy I Fell Through the Earth – Art Mix*. And then there are those using AI to help create entire albums, like Taryn Southern with *I AM AI*.

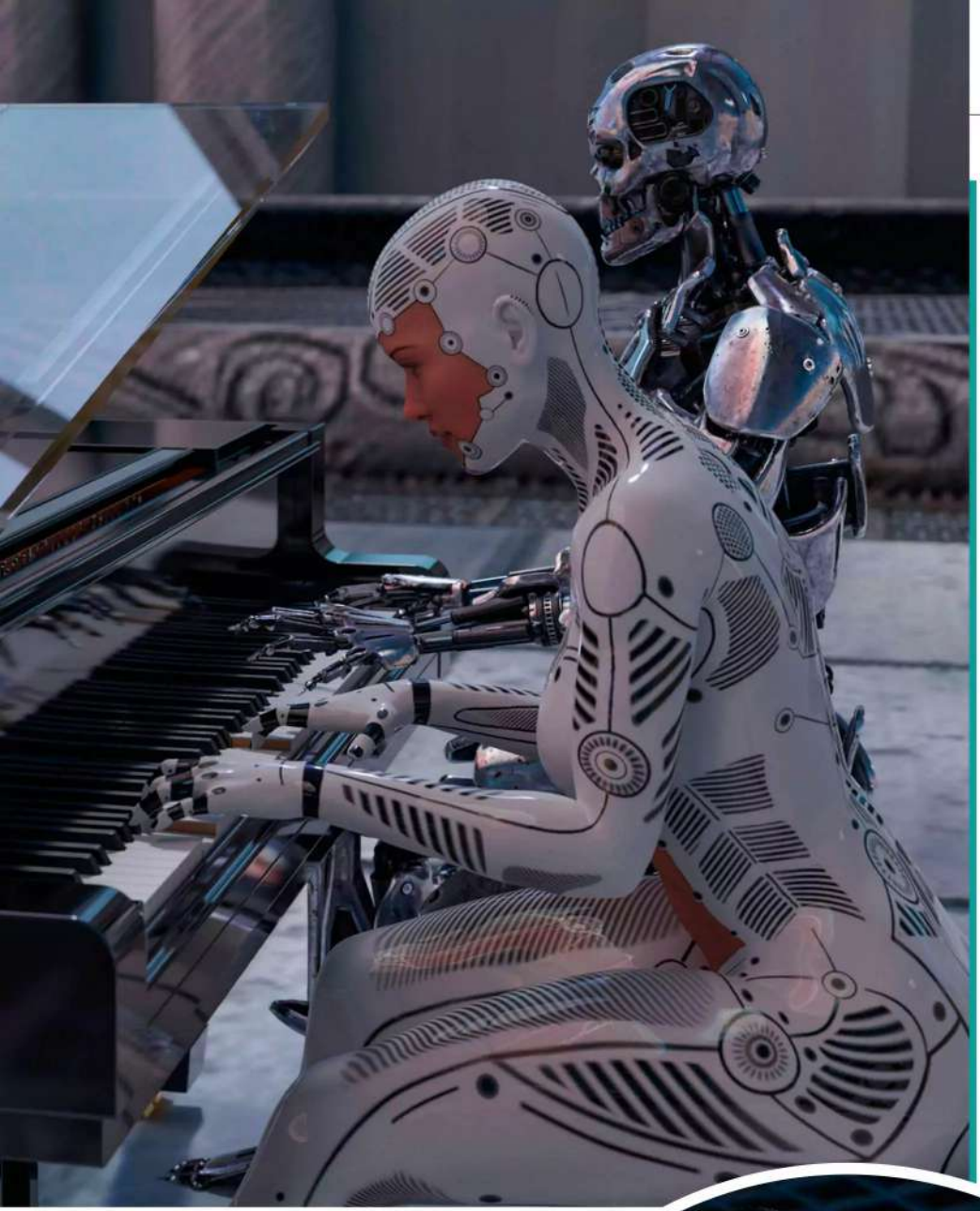
With AI advances showing no signs of slowing down, it won't be long before a computer can be used to make new versions of every musical genre that are indistinguishable from human-composed pieces. AI can even innovate, creating new concepts and exploring new sounds that have never existed before. But like our languages, music is all about communication. Today AI has all the skills, but nothing to say. Only when we use it to help us express ourselves can its true value be felt. ***PB***



WHAT IS THE DEADLIEST OLYMPIC SPORT?

Despite the clear risks involved in sports like pole vaulting, javelin or boxing, surprisingly few deaths have occurred at the Summer Olympic Games. In fact, there are just three recorded deaths of athletes during past tournaments – two in cycling events and one during a marathon.

Injuries are frequent however. At the end of the 2008 Olympics, over 1,000 injuries had been reported. The events associated with the most injuries were football, taekwondo, and hockey. ***CA***



WHY DO ELITE DIVERS HAVE TINY TOWELS?

Diving often involves tucks and pikes, where the diver grips their legs. Wet hands and legs can be slippery, so towelling off before a dive is important. Since Olympic divers sit in a hot tub to keep warm between dives, they'll towel off and get wet again several times during a competition. The tiny sports towel (also known as a shammy) absorbs a lot of water and is very easy to wring out afterwards. Some divers also have a ritual of dropping their towel from the diving board into the water to help judge the distance. ***LV***

GETTY IMAGES X2, ALAMY X2

NUMBER GAMES

493
km/h

Top speed of a badminton shuttlecock. Outside the rifle range, it's the fastest travelling object at the Summer Games.

54.69

Number of Summer Olympics medals won per one million people in Finland – the most successful Olympic nation per capita (mainly due to results from 1908-1956).

6,400
Newtons

The estimated force of a taekwondo spinning kick. Research suggests a blow of 2,450N has a 50 per cent chance of fracturing the average human forehead.

53
years

Time since athlete Bob Beamon set the Olympic long jump record (8.90m) in 1968, now the longest-held Olympic record.

178,000
joules

Estimated output of an international rower in five and a half minutes. This is enough energy to power an LED bulb for over 14 hours.

QUESTION OF THE MONTH

DO WOMEN MAKE FOR BETTER ENDURANCE ATHLETES THAN MEN?

You only need to think of any marathon you've watched to assume that men tend to outperform women in sport.

But an interesting recent review published in the journal *Sports Medicine* has reignited the discussion. It highlighted that the male-female performance gap in ultra-endurance competitions (events typically more than six hours) is as low as 4 per cent, while it's around 10 per cent in traditional endurance sport. And the difference seems to reduce the longer the event becomes, to the point that women even outperform men when it comes to events like ultra-distance swimming. Just look at the finishing times for the 45.8km Manhattan Island marathon swim. On average over the past 30 years, the best women have been 12 to 14 per cent faster than the best men.

There's lots of speculation as to why women might make better ultra-endurance athletes. If we look at the physiology, men tend to have more type II ('fast twitch') muscle fibres, which are good for high power output sports such as sprinting. Women have more type I ('slow twitch' or oxidative) muscle fibres, which produce less force but are more resistant to fatigue – ideal for ultra-endurance events.

Another theory is that women are better than men at burning fat for fuel and so they have spare essential carbohydrate stores. This would mean they're less likely to hit 'the wall' in a race (the point where glycogen is depleted). Other studies show that women are more likely to keep a consistent pace, instead of going too hard too soon.

Sports psychologists have also suggested that women are generally better at bearing pain, reframing feelings such as fatigue and enjoying the process rather than obsessing over the outcome – all of which might lead to a better performance.

As persuasive as these theories are, it's difficult to be certain. Ultra-endurance events are niche and the small numbers of women participating make extrapolation challenging, and it's rare to find direct comparisons with men. Hopefully this will change over time. ***NM***

EMAIL YOUR QUESTIONS TO **QUESTIONS@SCIENCEFOCUS.COM**

COULD ANYONE BECOME AN OLYMPIAN WITH ENOUGH PRACTICE?

Although many say it takes 10,000 hours of practice to become an expert in any field, research shows that not everyone has what it takes to become an Olympian or Paralympian.

We can all improve performance through dedicated practice, but genetic factors, influencing both brawn and brains, probably make the difference between 'good' and 'great' sportspeople. A 2016 analysis found that a mere 18 per cent of athletes' sporting ability was explained by the amount they'd practised; for athletes competing at the international level, this number dropped to 1 per cent.

Sporting success is also affected by factors you can't control, such as when you were born. For example, in the 2010-11 UEFA youth football tournaments, 43 per cent of players had birthdays between January and March (those born early in the selection period), compared to just 9 per cent born from October to December.

Children who are older when they start school might have a sporting advantage over younger classmates in

WHY DOES FINISHING SECOND FEEL SO MUCH WORSE THAN THIRD?

If you could choose, ahead of a big competition, whether you finish third or second, you'd choose second, right? Of course – and yet a study from the mid-1990s, based on analysis of athletes' emotional displays at the Barcelona Olympics, found that bronze medallists showed more positive emotion than silver medallists (with gold medallists happiest).

The most popular explanation is that silver medallists engage in a specific form

GETTY IMAGES X2, ALAMY, ILLUSTRATION: DANIEL BRIGHT

terms of size, strength or confidence, but many sports psychologists suggest the benefits of birth month are also a result of social factors, such as how teachers perceive their ability.

Contrary to the idea that it's important to start young, studies have shown that concentrating too intensely on one skill from a young age could be detrimental. For example, a Danish study found that elite athletes chose their specialism later and trained less in childhood than near-elite athletes. What set the elite athletes apart was intensifying their training in their late teens.

So, perhaps the best path to becoming an Olympian is to try many hobbies as a child and later focus on activities where you find natural ability and – most importantly – enjoyment. ***CA***

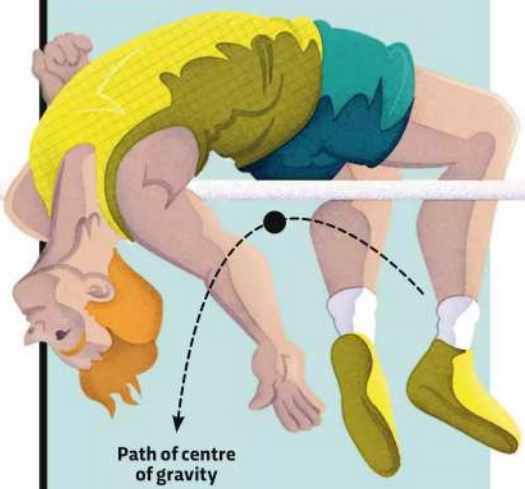
of 'counterfactual thinking' – that is, they regret missing out on what might have been, if only they'd pushed a little harder. In contrast, those in third place compare downwards and are relieved that they managed to earn a medal at all.

Later research conducted at the London 2012 Olympics seemed to back up this interpretation – among gold and bronze medallists, the better their performance, the happier they looked. But this wasn't the case for those who came second, perhaps because the better their performance, the greater their regret at not having won.

More recently, a study of athletes at the Rio Olympics actually found negligible differences in the happiness displays of silver and bronze medallists, but analysis of their post-competition interviews confirmed it really does suck to come second – the silver medallists engaged in far more talk about what might have been.

In short, if you ever find yourself miserable in second place, try taking a leaf out of the bronze medallists' playbook and be grateful you performed as well as you did! ***CJ***

HOW DOES THE FOSBURY FLOP WORK?



From a physics point of view, a high jump is all about moving energy and momentum. There's the energy of motion (kinetic energy) that the athlete acquires in their run-up. Then there's the gravitational potential energy, which increases with their height above the ground. Specifically, the potential energy depends on the height of the athlete's 'centre of mass', the average position of all the matter in their body.

To make a successful jump, kinetic energy needs to be converted into potential energy. And the maximum amount of potential energy sets the maximum height the athlete's centre-of-mass can achieve. But the genius of the Fosbury Flop (named after American athlete Dick Fosbury) is that it allows the athlete to clear a bar higher than the maximum height of their centre-of-mass. The athlete's centre-of-mass actually passes *under* the bar, as the athlete rotates around it.

To do all this, the athlete applies enormous force to the ground on take-off. This gives them both upward momentum, so their kinetic energy starts being converted into potential energy, and a rotational momentum around their centre-of-mass, which (with skill) can enable their head and shoulders to sneak over the bar while their feet are below it. This all means their average height is never higher than the bar, even though they pass over it. ***JB***

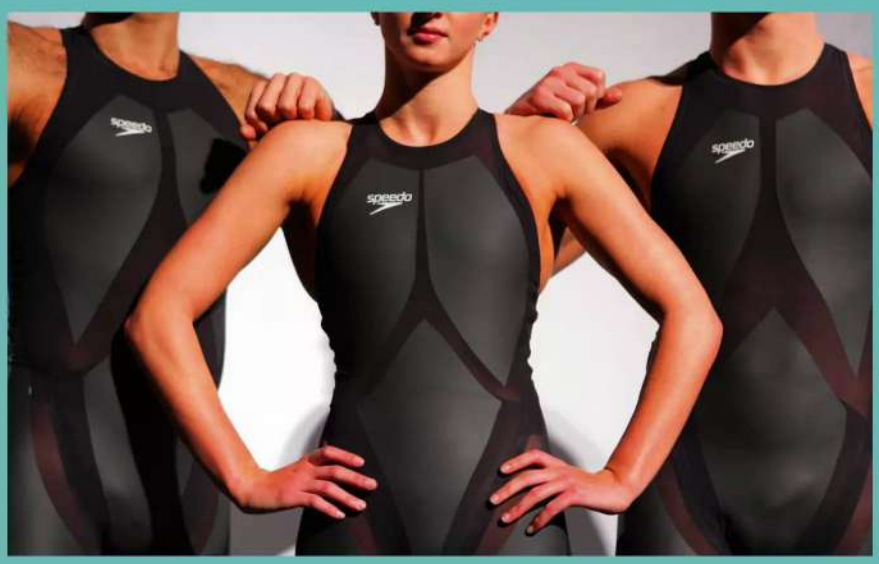
THE EXPLAINER

ARE HIGH-END RACING SHOES TECHNOLOGICAL DOPING?

WHAT RUNNING SHOES HAVE BEEN BANNED FROM THE TOKYO OLYMPICS?

In October 2019, Kenya's Eliud Kipchoge did what no human had done before and ran a marathon in under two hours. His 1:59:40 time came via an average speed of 21.18km/h (just try that for 30 seconds next time you're on a treadmill). But some argue the unofficial record partly derived from the Nike Alphafly shoes he was wearing. The Alphaflys, or "the shoe that broke running", as sports scientist Dr Ross Tucker called them, contain tech designed to deliver greater energy return and speed. Thanks to a trio of carbon plates and a cutting-edge midsole (the cushioning above the tread), peer-reviewed studies – albeit funded by Nike – claimed the shoe served up a 4 per cent increase in running efficiency and an estimated 3.4 per cent in speed.

However, new guidelines unveiled by World Athletics back in January 2020 saw the Alphaflys banned from elite competition. These new rules outline a shoe must have no more than one carbon-fibre plate, with midsole height not exceeding 40mm. But the story doesn't end there. Nike has released an altered version, the Vaporfly, which adheres to the new regulations and the shoe took 31 of the 36 podium positions at major marathons in 2019. Proponents laud Nike's innovation; critics say it's technological doping.



WHAT IS TECHNOLOGICAL DOPING ANYWAY?

The World Anti-Doping Agency (WADA) is best known for battling drug cheats. But its remit covers sports equipment too, and WADA will suggest a sport's governing body prohibits a particular item if it's deemed to be "against the spirit of the sport". But since most kit is designed to enhance performance, many items fall into a grey area, like Speedo's LZR Racer swimsuit (left), for example. The body-length suit uses textures based on shark skin to increase buoyancy. At the 2008 Beijing Olympics, 23 out of the 25 swimming records broken came from athletes wearing the LZR Racer. The suit was banned by swimming's governing body FINA (Fédération Internationale de Natation) in 2009.

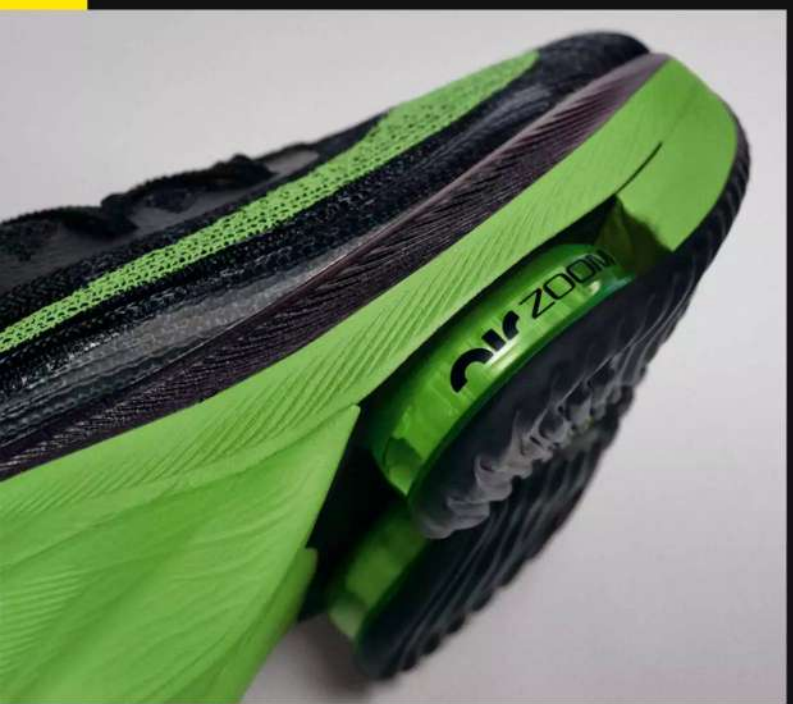
ALAMY X3, GETTY IMAGES, NIKE

HOW DOES THE NIKE VAPORFLY WORK?

On the face of it, the legal Vaporflys resemble a traditional shoe. But subtle differences combine for a significant difference. According to the *British Journal Of Sports Medicine*, the carbon-fibre plate, midsole material and midsole thickness are at the heart of the Vaporfly's efficiency.

The full-length plate increases the shoe's stiffness and acts as a lever to cut work at the ankle. This, Nike-funded but peer-reviewed studies claim, increases running efficiency by 1.5 per cent. On its own, the carbon plate's stiffness might deliver an uncomfortable feel, but this is offset by the thickness of midsole, which measures 31mm at the heel. Such a thick midsole would add weight over a traditional race shoe, but doesn't because it's made with a polyamide block elastomer called Pebax foam. More recent models also feature air pods as an extra suspension system.

It's difficult to pin down the collective advantage each element grants. But for some runners, the stability, energy efficiency and comfort the shoes provide is more beneficial than others – improvements in run times range from 6 per cent to absolutely nothing, according to the *British Journal Of Sports Medicine*.



IS 'SHOE FAIRNESS' EVEN POSSIBLE?

With commercialism the driving force, shoe fairness simply isn't possible. Nike's revenue grew 9 per cent in 2020, hitting the $11.24bn-mark (£7.9bn), with online purchases of its footwear a big driver. Even the considerable £250+ price tag for the Alpha/Vaporfly shoes didn't deter performance-seeking recreational runners.

Nike's secured a number of patents with the Vaporfly including the curvature of that full-length carbon plate. And while competitors such as Adidas and Saucony have followed suit, do their different shapes and different lengths of carbon afford the same advantage or has Nike beaten them to it? If a marathon runner wearing Adidas's equivalent shoes covers the 26.2-mile distance in 1:57:00, will Nike cry foul and play the technological-doping card?

It's a competitive quagmire, though one World Athletics (track and field's governing body) has gone some way to navigating this by limiting the midsole height to 40mm.

WHAT OTHER TECHNOLOGY COULD BOOST RUNNING PERFORMANCE IN THE FUTURE?

As the disparity in performance improvements for runners wearing the Vaporfly showed, differences such as arch shape, foot width and run gait all impact the proficiency of a shoe. So bespoke footwear is the ideal. And it's happening with Adidas using 3D foot-scanning technology and 3D printing to produce its prototype Futurecraft run shoe. This has progressed to the Strung shoe, slated to launch in late 2022.

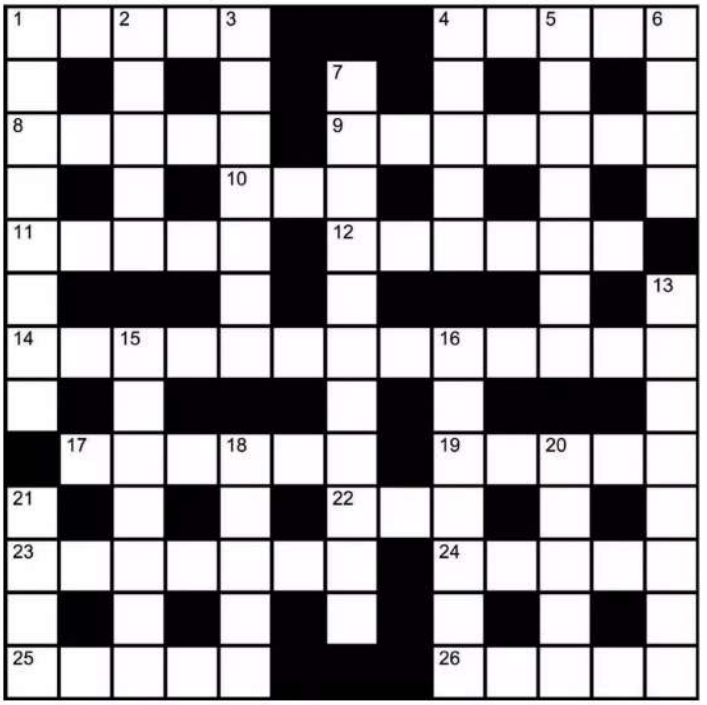
In future, tech could be used to help you run quicker by lowering your perceived exertion. This revolves around brain manipulation using transcranial direct current stimulation (tDCS), which is already growing in popularity. The idea is that a low current sent through your grey matter teaches your brain to maintain stronger neural signals as you flag, resulting in faster times. tDCS products are already on the market making big claims that aren't backed by independent evidence.

by JAMES WITTS

James is a sports science journalist and the author of The Science Of The Tour De France *and* Training Secrets Of The World's Greatest Footballers.

CROSSWORD

GIVE YOUR BRAIN A WORKOUT



ACROSS

1 Where you may acquire education and elegance (5)
4 A hundred and one took in performance, and they're prickly (5)
8 Roam around after a scent (5)
9 Uncontrolled sheep puts pressure on worker (7)
10 Peg is a character, by the sound of it (3)
11 Handle a nice surprise (5)
12 Clear problem with current cake (6)
14 Wave weapon at English article written by bard (13)
17 Leave ship with Greek character, returning chat (6)
19 Putin's unusual contribution (5)
22 Compendium includes its own writer (3)
23 Soldier unwilling to share (7)
24 Furious buccaneer loses head (5)
25 Intrigued elves have to investigate (5)
26 Background player is surplus (5)

DOWN

1 Berate pursuit – it's back in (8)
2 Sailor takes poem home (5)
3 Pay to go round a city (7)
4 Arrived and left an animal (5)
5 Parasites spotted behind tea cup (7)
6 I return to a small amount (4)
7 Eco-friendly vigour for every vegetable (5,6)
13 Name a hat – awful and abhorrent (8)
15 An informal gathering is inconsiderate (7)
16 Stupid when one joins bigger number (7)
18 Small fish has a drink (5)
20 Breathe heavily, left inside factory (5)
21 Betting journalist was rushed (4)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

NEXT ISSUE

EGGS-TRAORDINARY!

Try not to crack up when you lay your eyes on nature's weirdest eggs.

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A SCIENTIST'S GUIDE TO LIFE

COLD-WATER SWIMMING

IF TAKING A DIP IN A MURKY LAKE DOESN'T SOUND LIKE YOUR THING, THEN READ ON. AS **DR HEATHER MASSEY** EXPLAINS, THE BENEFITS OF COLD-WATER SWIMMING ARE BEGINNING TO BECOME CLEARER

IT'S COLD OUTSIDE.

Lakes, rivers, the sea… if you live in the UK, any outdoor, non-heated swimming is cold-water swimming. I do it because I enjoy being outside and it's something I've always done.

LOTS OF PEOPLE REPORT POSITIVE EFFECTS FROM DOING IT.

There's lots of anecdotal evidence. People say cold-water swimming can help with depression, pain and migraines. Some menopausal women find a decrease in the severity or number of hot flushes. These personal experiences are important, but we lack the scientific studies to back them up. This is starting to change. We want to know who benefits from cold-water swimming, what the effects are and what the underlying mechanisms are.

WHAT ELSE COULD IT HELP?

One study, from Cambridge University, hinted that cold-water swimming might help stave off dementia. Compared with members of a Tai Chi club, winter swimmers at London's unheated Parliament Hill Lido were found to have higher levels of a protein that helps protect against neural degeneration.

COLD WATER HAS A BIG IMPACT.

The gasping for air, the rise in heart rate and the increase in blood pressure… these are all parts of the cold shock response from entering cold water. This can be dangerous for people with certain underlying health conditions. It's also possible to breathe water into your lungs and drown. Last year in the UK, around 250 people died from accidental immersion in cold water.

SWIM SAFE.

If you have any medical issues, check with your GP before you start cold-water swimming. Never swim alone. Find local groups to swim with. They're friendly and full of local knowledge.

DON'T FORGET YOUR SWIMSUIT.

In the height of summer, all you need is a swimming costume, a towel and maybe some flip flops. If you want to spend longer in the water or are swimming in winter, you might wear a wetsuit or neoprene gloves. It doesn't have to be expensive and will also help to keep you warm after you leave the water.

GET IN SLOWLY.

Before you get in, work out how you'll get out. If the exit is tricky, make sure to give yourself enough time. Then when you're ready, get into the water slowly. This minimises the cold shock response. If you can't ease in gently, splash water on your legs, then arms, then torso and then get in. Take a few minutes to get over the cold shock response before you start to swim. If you can talk in full sentences, you have full control of your breathing.

MAKE IT A QUICK DIP.

Unless you're an experienced cold-water swimmer, keep it brief. Five to ten minutes is plenty. We don't know the optimum time, temperature or frequency of cold-water swimming needed to reap any potential benefits, but we do know that you'll fatigue more quickly in cold water. So if you're not enjoying it, get out.

GET OUT BEFORE YOU'RE READY.

Exit the water knowing that you'd like to have stayed in longer. Get dry, dressed and warm. It's always a good idea to bring of flask of something warm to hold on to and drink afterwards. In time, science may confirm the health benefits of cold-water swimming, but for now, just enjoy it and be safe. **SF**

DR HEATHER MASSEY

Heather is a cold-water swimmer and researcher at the Extreme Environments Laboratory at the University of Portsmouth.

Interviewed by Dr Helen Pilcher.

NEED TO KNOW...

1. If you have any medical concerns, check with your GP before you start cold-water swimming.
2. Get in slowly to adjust to the cold, but make sure you can get out easily before the cold makes doing so difficult.
3. Getting out early is better than staying in too long. And bring a towel, warm clothes and a hot drink.

ILLUSTRATION: MATT HARRISON CLOUGH

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